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Sarmatian paleoecological environment of the Machów Formation based on the quantitative nannofossil analysis — a case study from the Sokołów area (Polish Carpathian Foredeep)

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Abstract: The Machów Formation belongs to a supra-evaporitic succession of the Polish Carpathian Foredeep Basin (PCFB). Our studies were concentrated in the eastern part of the PCFB, north of Rzeszów. 33 samples were collected from five boreholes, at depth intervals as follows: Stobierna 2 — 1016–1338 m; Stobierna 3 — 715–1669 m; Stobierna 4 — 1016–1238 m; Stadnicka Brzóza 1 — 350–356 m and 1043–1667 m; Pogwizdów 2 — 1161–1390 m. The obtained biostratigraphical data gave evidence for the upper part of the NN6 (the Early Sarmatian) and for the NN7 (the lowermost part of the Late Sarmatian) Zones. All the nannofossil assemblages from Stobierna 2, Stobierna 4 and Pogwizdów 2 were assigned to the NN6 Zone. In the Stobierna 3 borehole the interval 1669–1113 m was assigned to NN6, whereas assemblages from depth interval 843–715 m belong to NN7 Zone. In Stadnicka Brzóza 1 interval 1667–1043 m belongs to NN6 Zone and interval 350–356 m to NN7 Zone. The *Discoaster exilis* Zone (NN6) was defined by the presence of *Reticulofenestra pseudoumbilica*, *Sphenolithus abies*, *Helicosphaera walbersdorfensis* and absence of *Discoaster kugleri*. The *Discoaster kugleri* Zone (NN7) assignment was based on the abundance of *Coccolithus miopelagicus* (> 10 μm), used as an alternative species essentially confined to that interval, and absence of *Catinaster coalithus*. The observed nannoplankton assemblages are predominantly composed of a high number of redeposited material, abundant long-ranging taxa and taxa resistant to carbonate dissolution. General assemblage compositions, obtained from quantitative data, indicate shallow near-shore environment and could confirm basin isolation.

Key words: Miocene, Polish Carpathian Foredeep, paleoecology, biostratigraphy, calcareous nannofossil quantitative and qualitative analysis.

Introduction

The Polish Carpathian Foredeep Basin (PCFB) (Fig. 1) about 320 km long and up 100 km wide is part of the big sedimentary basin, which extends from the Danube River in Austria to the Iron Gate on the Danube River in Romania (see Oszczypko 1998; Oszczypko et al. 2006). The Polish Carpathian Foredeep, developed at the front of the overriding Carpathian nappes, is predominantly filled with marine clastic sediments of the Miocene age up to 3 km thick. These deposits are underlain by the basement of the West and East European Platform, composed of Precambrian, Paleozoic and Mesozoic rocks. According to geophysics and well data, the platform basement with Miocene molasse cover dips southwards underneath the Outer Carpathian nappes to a distance of at least 50 km (Oszczypko & Ślączka 1985; Oszczypko 2006). The PCFB can be subdivided into inner and outer foredeep. The inner foredeep, composed mainly of the Lower Miocene deposits, is now buried beneath the Carpathian nappes, while the outer foredeep, composed exceptionally of Middle/?Upper Miocene deposits, is located north of the Carpathian frontal thrust.

The Miocene deposits of the PCFB are poorly exposed. A few, natural exposures of the Miocene strata are situated mainly along the northern margin of the foredeep. As a result, our present knowledge on the geological structure and stratigraphy of the PCFB is based on the borehole and seismic survey for hydrocarbon exploration.

In the course of these investigations the Sokołów-Smolarzyny, the gas-bearing area located NE of Rzeszów, have been thoroughly recognized (Figs. 2, 3) by 3D seismic survey, several boreholes and well logs (Krzywiec et al. 2008). The afore-mentioned studies enabled the construction of a new depositional model of this part of the Polish Carpathian Foredeep Basin (op. cit.). The aim of our study is to supplement this model with the results of the analysis of paleoecological environments based on calcareous nannofossils.

Previous works

The history of geological research on the Neogene deposits in the Southern Poland is almost 200 years old. A detailed review of these studies and the current state of knowledge have been presented by Peryt & Jasionowski (2004). In the outer part of the Carpathian Foredeep the beginning of the Miocene sedimentation is associated with the Early Badenian transgression and the deposition of the Dębowiec trans-

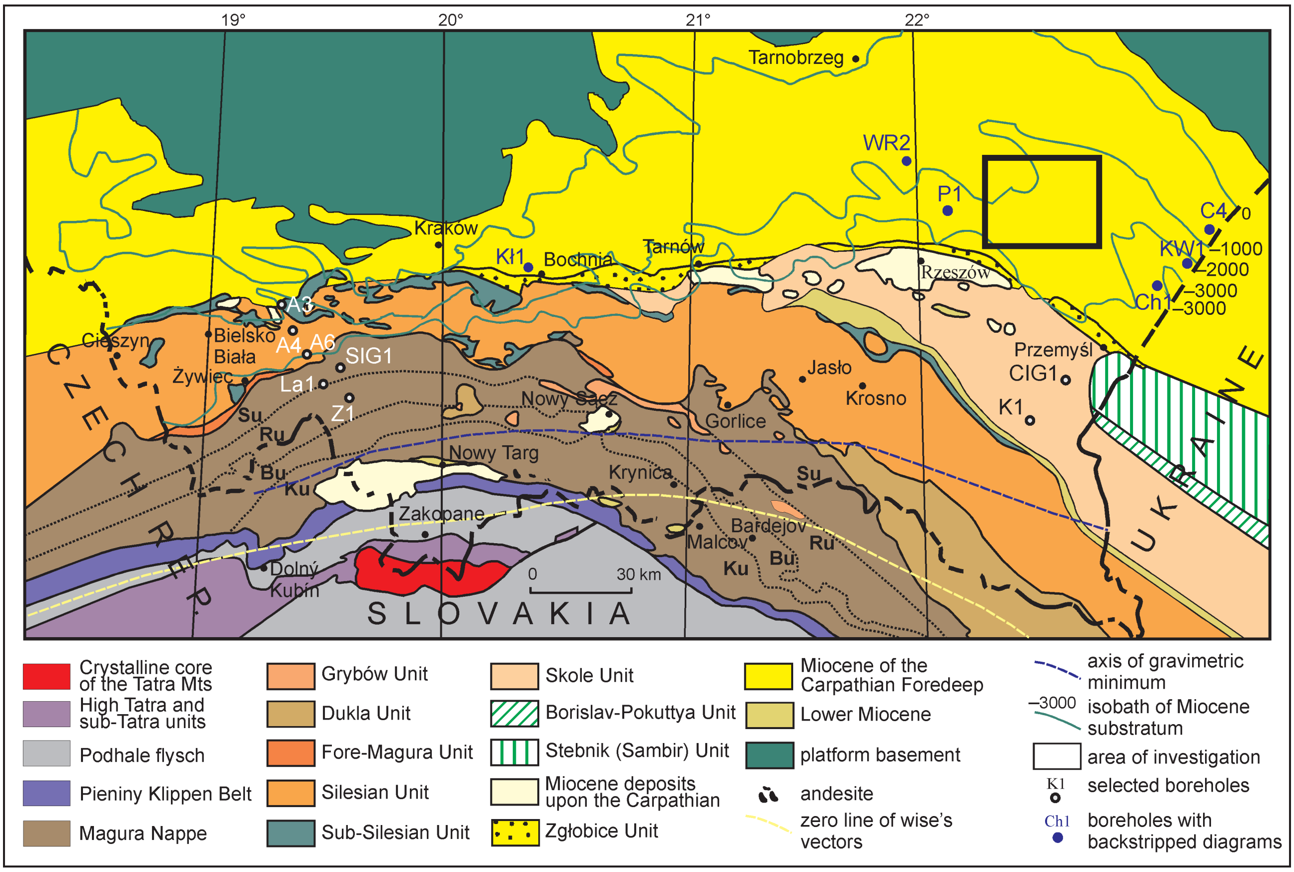
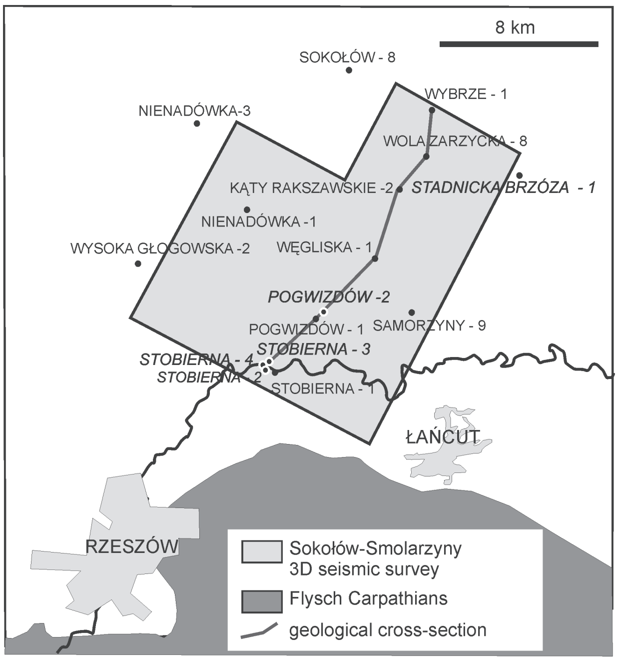


Fig. 1. Sketch-map of the Polish Carpathians and their foredeep (after Oszczypko 2006). Abbreviations: **Su** — Siary, **Ru** — Rača, **Bu** — Bystrica, and **Ku** — Krynica subunits of the Magura Nappe. Boreholes: A3 — Andrychów 3; A4 — Andrychów 4; A6 — Andrychów 6; La — Lachowice 1; Z1 — Zawoja 1; SIG1 — Sucha IG1; Kł1 — Kłaj 1; Ła1— Łapanów 1; WR2 — Wola Raniżowska 2; P1 — Palikówka 1; K1 — Kuźmina 1; CIG1 — Cisowa IG1; Ch1 — Chotyniec 1; KW1 — Kobylnica Wołoska 1; C4 — Cetynia 4. Main groups of tectonic units of the Outer Western Carpathians: Marginal Group (external): Borislav-Pokuttya, Stebnik (Sambir) and Zgłobice Units; Middle Group (central): Grybów, Fore-Magura, Dukla, Silesian, sub-Silesian and Skole Units and Magura Group (internal).



gressive conglomerates (see also Oszczypko et al. 2006), known from the Cieszyn and Wadowice area, both at the front of the Carpathian overthrust as well as beneath the Carpathians. The Middle Miocene marine transgression, flooded both the foredeep and marginal parts of the Carpathians.

The Badenian deposits in the outer part of the foredeep are traditionally subdivided into Lower Badenian (sub-evaporitic), Middle Badenian (evaporites) and Upper Badenian (supra-evaporitic) beds (Fig. 4). This subdivision differs from the recent Early/Middle Miocene integrated stratigraphy of the Central Paratethys (Piller et al. 2007; Hohenegger et al. 2009, 2011, see also Oszczypko & Oszczypko-Clowes 2011). According to these new propositions, the Badenian stage should be subdivided as follows: Early Badenian (16.30–14.89 Ma), Middle Badenian–Moravian (Lower and Upper Lagenid Zone; 14.89–13.82 Ma), and Late Badenian (Wielician 13.82–13.65 Ma and Kosovian: Bulimina-Bolivina Zone — 13.65–12.73 Ma). In this scheme, the boundary

Fig. 2. Locality of boreholes (after Krzywiec et al. 2008, simplified).

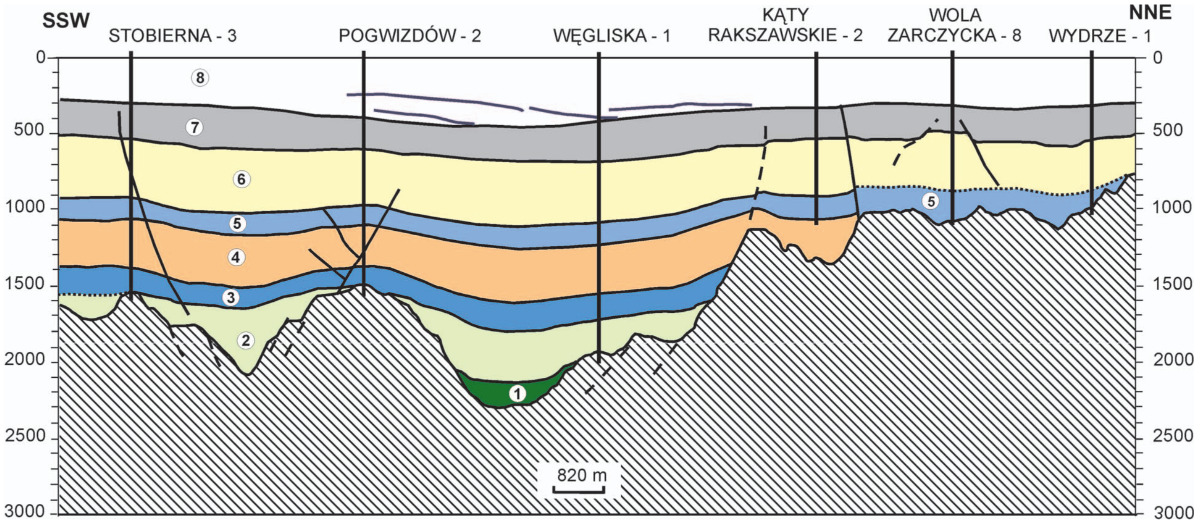


Fig. 3. Stobierna-Wydrze geological cross-section (after Krzywiec et al. 2008). Lithofacies: **1** — evaporites, **2** — lower fine-grained complex, **3** — turbiditic, **4** — lower deltaic deposits, **5** — inner-deltaic deposits, **6** — upper deltaic deposits, **7** — lagoonal and shallow marine deposits, **8** — Quaternary and uppermost Sarmatian (undivided).

NN4/NN5 at 14.89 Ma is located inside *Helicosphaera ampliaperta* LO (15.50–14.53 Ma), while the NN5/NN6 boundary (13.65 Ma) coincides with *Sphenolithus heteromorphus* LO. Subsequently, the Badenian/Sarmatian boundary is placed at 12.73 Ma.

The Badenian strata rest directly on the platform basement, except in the inner foredeep, where they cover the Lower Miocene deposits. Usually, the "Lower Badenian" (Ney 1968) begins with a thin layer of conglomerates; however, in the western part of the foredeep the Dębowiec Conglomerates attain thicknesses of up to 100 m. The conglomerates pass upwards into dark, clayey-sandy sediments of the Skawina Formation. The thickness of the "Lower Badenian" deposits is variable, reaching up to 1000 m in the western inner foredeep (Fig. 4), whereas in the remaining parts of the foredeep it rarely exceeds 30–40 m (Ney et al. 1974). The sedimentation of the Skawina Formation began in the inner foredeep with the *Praeorbulina glomerosa* Zone (N8), whereas in the outer foredeep it started with the *Orbulina suturalis* (N9 or N10) Zone (Garecka et al. 1996; Oszczypko 1998; Oszczypko et al. 2006). South of Kraków, the Skawina Formation has been pierced by the borehole Łapanów 1 (Fig. 1) beneath the Carpathian overthrust, at the depth of 1458–1765.5 m. This formation transgressively covers Jurassic limestones of the lower plate.

In the western part of the foredeep the Dębowiec Conglomerates are overlain by the Skawina Formation, while in other parts of foredeep this formation overlies directly the platform basement. In the Cieszyn-Bielsko area the thickness of this formation reaches 1000 m, while in the rest part of PCFB it decreases to 30–40 m or less. In the north-eastern part of the PCFB the Baranów Beds are an equivalent of the Skawina Formation (see Oszczypko et al. 2006). On the basis of foraminiferal studies the Skawina (Baranów) Formation has been included in the "early Badenian", whereas according to calcareous nannoplankton investigation the lower part of the formation belongs to the NN5 Zone, while the upper (sub-salt) part of the formation belongs to the NN6 Zone (Garecka et al. 1996; Andreyeva-Grigorovich et al. 1999, 2003; Peryt 1999; Peryt & Gedl 2010).

Higher up in the succession we find evaporites, which are developed in the sulphate–anhydrite and gypsum (Krzyżanowice Formation) and chloride (salt) facies (Wieliczka Formation) (Garlicki 1968) (Fig. 4). The sulphate facies strongly predominates in the entire Carpathian Foredeep, and its thickness ranges from 10–30 m, but usually does not exceed several meters. Both autochthonous and allochthonous chloride facies occur in a narrow peri-Carpathian zone and to the east of Tarnów also beneath the Carpathian nappes. According to nannoplankton studies the evaporites belong to the lower part of the NN6 Zone (Peryt 1997; Peryt et al. 1997, 1998; Andreyeva-Grigorovich et al. 2003, 2008; Peryt & Gedl 2010).

In the Bochnia Mine, the Wieliczka Salt Formation contains the WT-3 tuffite horizon, located ca. 37 m above the top of the Skawina Formation. The radiometric age of this tuffite has been determined at 13.60+/–0.07 Ma (De Leeuw et al. 2010, see also Bukowski et al. 2010). The evaporites are overlain by a sandy-silty series that are attributed to the Upper Badenian (Kosovian) and Sarmatian (Fig. 4).

Between Kraków and Tarnów the Chodenice Beds occur above the evaporites. They comprise marly claystones with sporadic sandy intercalation. The upper part of the Chodenice Beds contains several tuffite layers (Van Couvering et al. 1981).

In the Sułków brick yard directly above the tuffite layers, nannoplankton belonging to the NN6/7 Zone (Andreyeva-Grigorovich et al. 1999) may indicate the boundary between the Badenian and Sarmatian. Between Tarnów and Dębica the lower part of the Chodenice Beds up to 600 m thick contain numerous sandy intercalations (Krzywiec 1997). To the north the thickness of the Chodenice Beds decreases to a few dozen meters. At the same time these beds are replaced by marly claystones (*Spirialis-Pecten* beds). Between Kraków

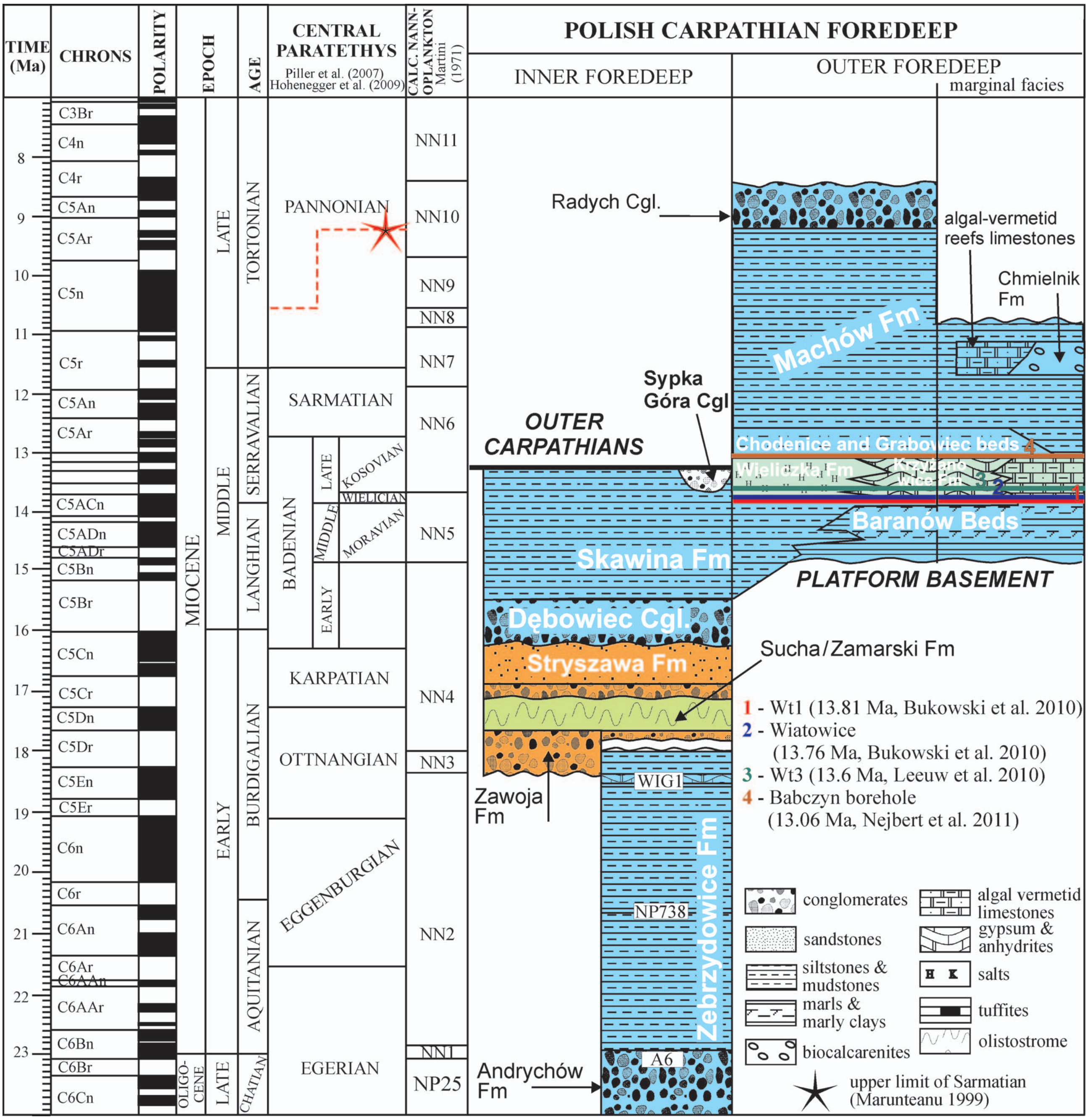


Fig. 4. Stratigraphic scheme of the Miocene deposits of the Polish Carpathian Foredeep Basin (after Oszczypko 1998; Oszczypko et al. 2006; Oszczypko & Oszczypko-Clowes 2011).

and Tarnów the Chodenice Beds are overlain by the sandy layer of Grabowiec Beds, several hundred meters thick. In the Kraków area the basal part of the Grabowiec Beds are developed as the Bogucice Sands (Porębski & Oszczypko 1999).

East of the Dunajec River the evaporites are overlain by clayey sandy deposits known as the Machów Formation (Alexandrowicz et al. 1982). The youngest member of this formation belongs to the Krakowiec shales (beds). Their thickness ranges from several hundred meters in the region of Tarnów to over 2500 m in the vicinity of Przemyśl. These beds were traditionally included in the Lower Sarmatian. More recent studies by Paruch-Kulczycka (1999) show that the upper part of these beds belongs to the Late Sarmatian (Chersonian, cf. Gaździcka 1994; Król & Jeleńska 1999).

The problem of the Badenian/Sarmatian boundary in the PCFB has been recently discussed by Nejbert et al. (2010) (see also Oszczypko & Oszczypko-Clowes 2011). It was introduced by results of the Babczyn 2 borehole, drilled in the NE part of the PCF (near the Polish-Ukrainian border). In this borehole, more than 32 m of evaporite gypsum of the Krzyżanowice Formation (Wielician), the 9.4 m-thick *Pecten* beds, related to the post-evaporate Kosovian transgression, and the 12.6 m-thick Sarmatian *Syndesmya* beds were drilled. The boundary between the *Pecten* and *Syndesmya* beds is roughly coincident with the appearance of the endemic Sarmatian foraminifera *Anomalinoides dividens* Łuczkowska. In the *Pecten* beds (3.4 m above the gypsum), a tuffite layer was found and dated ($^{40}Ar/^{39}Ar$) to an average age of 13.06±0.11 Ma (Nejbert et al. 2010).

In the Sokołów-Smolarzyny area (see Krzywiec et al. 2008) cores material have been studied from the following wells: Stobierna 2, Stobierna 3, Stobierna 4, Brzóza Stadnicka 1 and Pogwizdów 2 (Fig. 2). All of these wells have been located on the Lower San High, within the so-called "anhydrite missing Rzeszów Island" (Komorowska-Błaszczyńska 1965; Oszczypko et al. 2006). The drilled profiles of these wells belonged to the Machów Formation, up to 2000 m thick. On the basis of core description, the following lithofacies were distinguished as follows: hemipelagites, thin-bedded heteroliths, classical turbidites and thick-bedded sandstones (Krzywiec et al. 2008). The seismic, well data and core analysis enable us to distinguish (from base to top of the formation) the following lithofacies complexes: lower fine-grained, turbiditic, lower deltaic, interdeltaic, upper deltaic, nearshore to estuarine, and upper undivided ones. On the basis of calcareous nannoplankton studies, the Sarmatian (upper part of NN6 to NN7 Zones) age of studied deposits were determined. Taking into account the lack of core material, the lowermost and uppermost complexes have not been studied (see Krzywiec et al. 2008).

Biostratigraphic studies of Machów Formation

One of the first references about the stratigraphic position of the Machów Formation originated from Łuczkowska's research (1964). Assignment of the age as Late Badenian–Early Sarmatian was based on foraminiferal associations. The Sarmatian floor was associated with common occurrence of *Cycloforina stomata* and *Anomalinoides dividens* Łuczkowska with simultaneous disappearance of the Late Badenian species. In 1966 Odrzywolska-Bieńkowa described the following foraminiferal zones: *Anomalinoides dividens* and *Elphidium hauerinum* within the Krakowiec beds. Three years later Jurkiewicz (in: Ney 1969) identified two Sarmatian foraminiferal zones and then Odrzywolska-Bieńkowa (1972) and Łuczkowska (1972) identified zones representing the Early and Middle Sarmatian. In 1994 in the Tarnobrzeg area (northeastern part of the Carpathian Foredeep) the calcareous nannofossils of the Machów Formation were studied by Gaździcka. On the basis of nannoplankton assemblages the age of the Machów Formation (the *Pecten* beds and Krakowiec clays distinguished) seems to be younger than the NN7 *Discoaster kugleri* Zone and corresponds to the NN8 *Catinaster coalitus* and NN9 *Discoaster hamatus* Zones. According to Czepiec (1997), the age of the Machów Formation is assigned to the Late Badenian–Late Sarmatian, what was based on foraminiferal associations (the Early Sarmatian *Anomalinoides dividens* horizon and the lower part of the Late Sarmatian *Protelphidium subgranosum* horizon).

Ślęzak (in Krzywiec 1997) assigned these deposits to the NN5/NN6 Zones. More precise assignment was impossible due to scarcity and low diversity of the Miocene species. In SE Poland, calcareous nannoplankton from the Baranów Beds was studied by Peryt (Peryt in Peryt et al. 1998). Described assemblages contained mainly the long-ranging species, whereas the index taxa were absent. However, the nannofossils assemblages from the anhydrite horizon (above the Baranów Beds) indicate an age not younger than the NN6 Zone (Peryt et al. 1998). In 1994 Gaździcka assigned the Baranów Beds to the NN6 Zone on the basis of the presence of *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Discoaster exilis*, *Reticulofenestra minutula* and *Reticulofenestra pseudoumbilica*, followed by the absence of *Sphenolithus heteromorphus* and *Discoaster kugleri.* Garecka & Jugowiec (1999) presented the results of biostratigraphic study of Miocene deposits in the Carpathian Foredeep concentrated on calcareous nannoplankton. The Machów Formation deposits, precisely Krakowiec Clays, are included in the NN5 Zone (Kupno area) and NN6 (Cegielnica/Dębica area), with exceptions concerning poor quality material, characterized by low diversity and high numbers of redeposited specimens. The upper part of the Krakowiec beds in the Jamnica S-119 borehole was assigned to the Pannonian (the early Late Miocene) by Paruch-Kulczycka (1999). Such age assignment was based on foraminifera and the camoebians studies.

In 1999 Olszewska summarized previous micropaleontological research (1995–1998) in the Carpathian Foredeep area. The Machów Formation (Alexandrowicz et al. 1982), described by Olszewska (1999), includes 5 informal subdivisions: the Chodenice Beds, the Grabowiec Beds, the *Pecten* beds, the *Spirialis* Clays Member, and the Krakowiec clays. Olszewska (1999) considers foraminiferal associations above *Anomalinoides dividens* horizon as less diagnostic and suggests revision of these data by nannoplankton assignment, which seems to be more precise. On the basis of foraminifera, the Krakowiec clays were assigned to the Late Badenian–Early Sarmatian (Olszewska 1999; Dziadzio 1999). The next foraminiferal studies provided by Olszewska (Olszewska in: Dziadzio et al. 2006) confirmed these results. Moreover, the younger deposits were also described and qualified to the Late Sarmatian (*Anomalinoides dividens*, *Varidentella reussi* and *Porosononion granosum* horizons).

Subsequent research, based on calcareous nannoplankton, was conducted by Oszczypko-Clowes in the Sokołów-Smolarzyny area (Oszczypko-Clowes in: Krzywiec et al. 2008) and provided more accurate results. The obtained data gave evidence for the NN6 Zone in the lower part of the Machów Formation profile and for the NN7 Zone in the upper part (Early and Late Sarmatian). The NN6 Zone was defined by the absence of *Sphenolithus heteromorphus* and *Discoaster kugleri* and by the presence of *Helicosphaera walbersdorfensis* and *Cyclicargolithus floridanus*. Assignment of the NN7 Zone was based on the presence of *Coccolithus miopelagicus* and *Calcidiscus macintyrei*. The oldest deposits belonging to the lower fine-grained complex, evaporites and possible subevaporites, were not studied because of lack of biostratigraphical documentation.

The latest micropaleontological studies (Garecka & Olszewska 2011) of the Middle Miocene deposits in SE Poland and Western Ukraine confirm the reliability of the foraminiferal zones described by Łuczkowska (1964), and high correlation

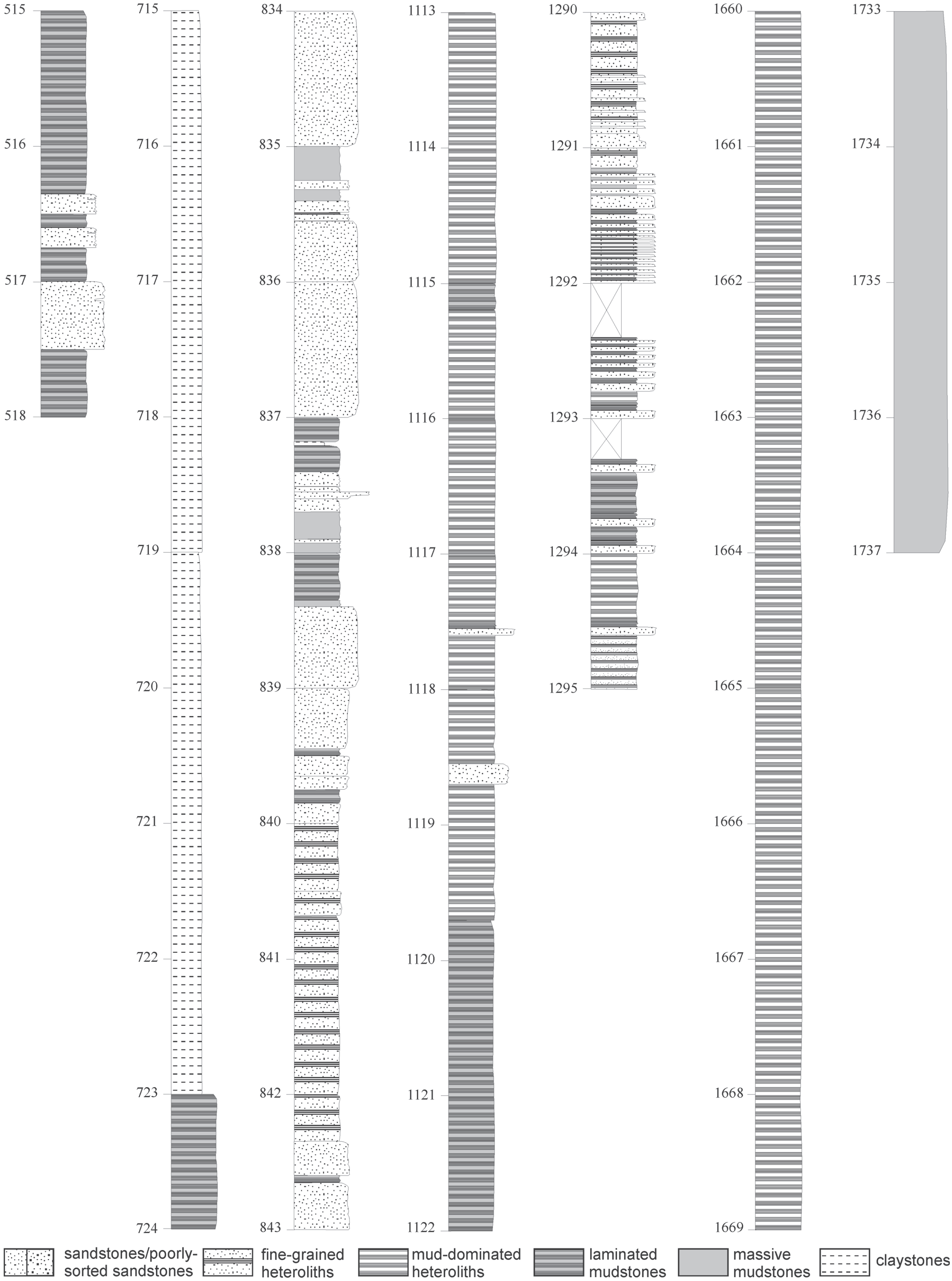


Fig. 5. Lithological log of the core material from the Stobierna 3 borehole.

degree between Polish and Ukrainian assemblages, what was also indicated by Łuczkowska (1964). This research also showed the similarity of calcareous nannoplankton associations from the Polish and Ukrainian part of the Carpathian Foredeep. In the assemblages of the upper part of the NN6 and the lower part of the NN7 Zone the gradual impoverishment of species was noticed (Garecka & Olszewska 2011).

Geological setting

In 2006 the authors profiled and sampled for the calcareous nannoplankton studies the core material from the boreholes: Stobierna 3 (515–524 m to 1733–1737 m, together 51 boxes) (Figs. 5, 6), Stobierna 4 (1016–1021 m to 1237–1238 m, together 22 boxes) (Figs. 7, 8), Stadnicka Brzóza 1 (350–356 m to 1687–1991 m, together 28 boxes) (Fig. 9). The short characteristic of core material is summarized in Table 1. We also collected samples from the Stobierna 2 and Pogwizdów 2 boreholes.

The studied area is located mainly within the so-called “Rzeszow anhydrite-less island” (Komorowska-Błaszczyńska 1965; Oszczypko et al. 2006). This allows us to include the thick Miocene (Upper Badenian/Sarmatian) sequence: 1707 m (Pogwizdów 2) to 1936 m (Stobierna 1) in the Machów Formation (Alexandrowicz et al. 1982; Jasionowski 1997).

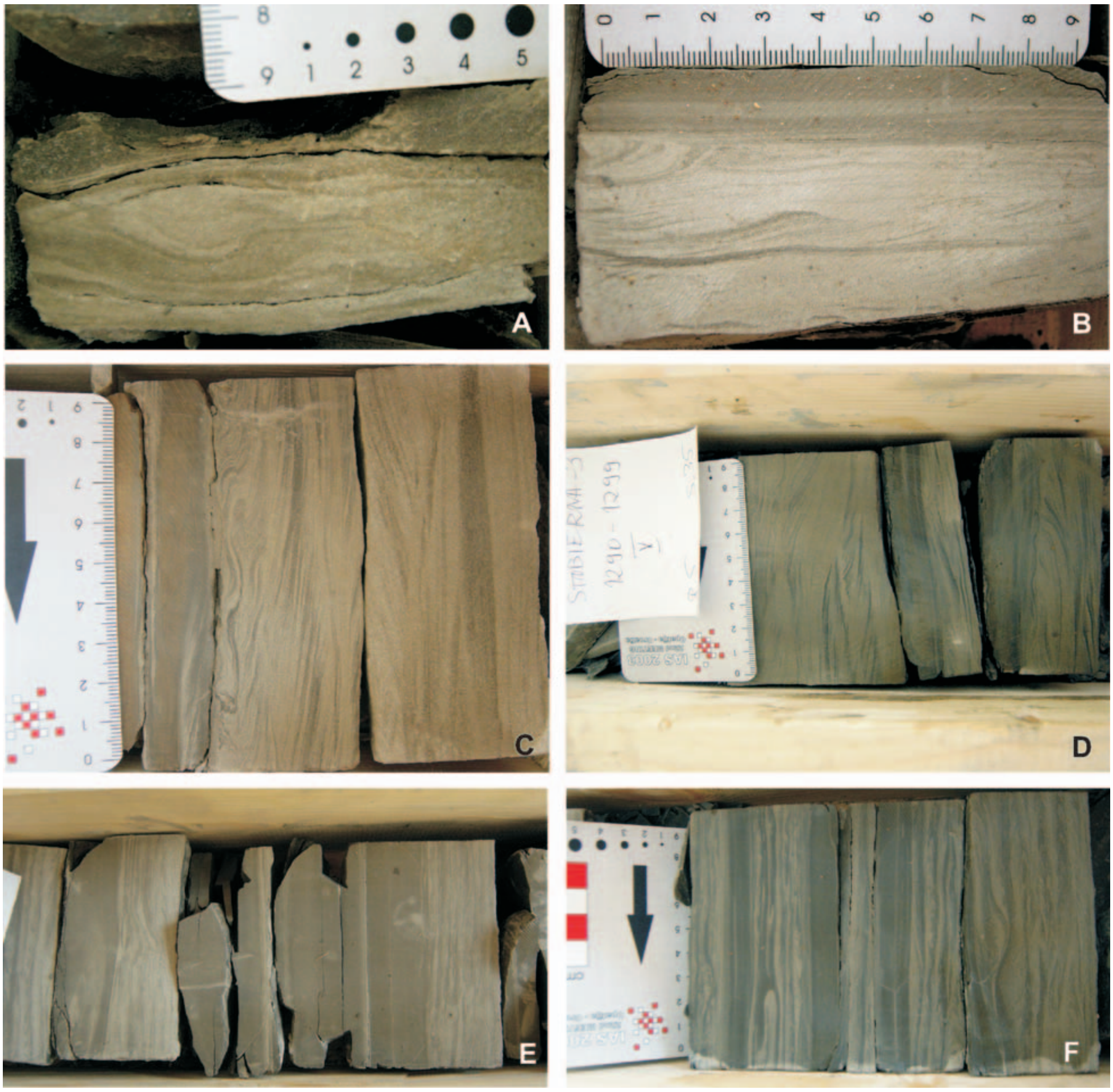


Fig. 6. Photographs of the core material from the Stobierna 3 borehole. Thin-bedded heteroliths. **A** — depth interval 834–843 m, IV— fine-grained silty heteroliths with discrete convolution; **B** — depth interval, 1113–1122 m, V — sandy/claystone thin-bedded heteroliths with horizontal and diagonal through lamination; **C** — depth interval 1290–1299 m, I — silty/mudstone, thin-bedded heteroliths with diagonal, stripped lamination; **D** — depth interval 1290–1299 m, V — silty/mudstone thin-bedded heteroliths with diagonal, stripped lamination; **E** — depth interval 1660–1669 m, V — silty heteroliths with horizontal lamination; **F** — depth interval 1660–1669 m, VII — silty/mudstone horizontal stripped lamination.

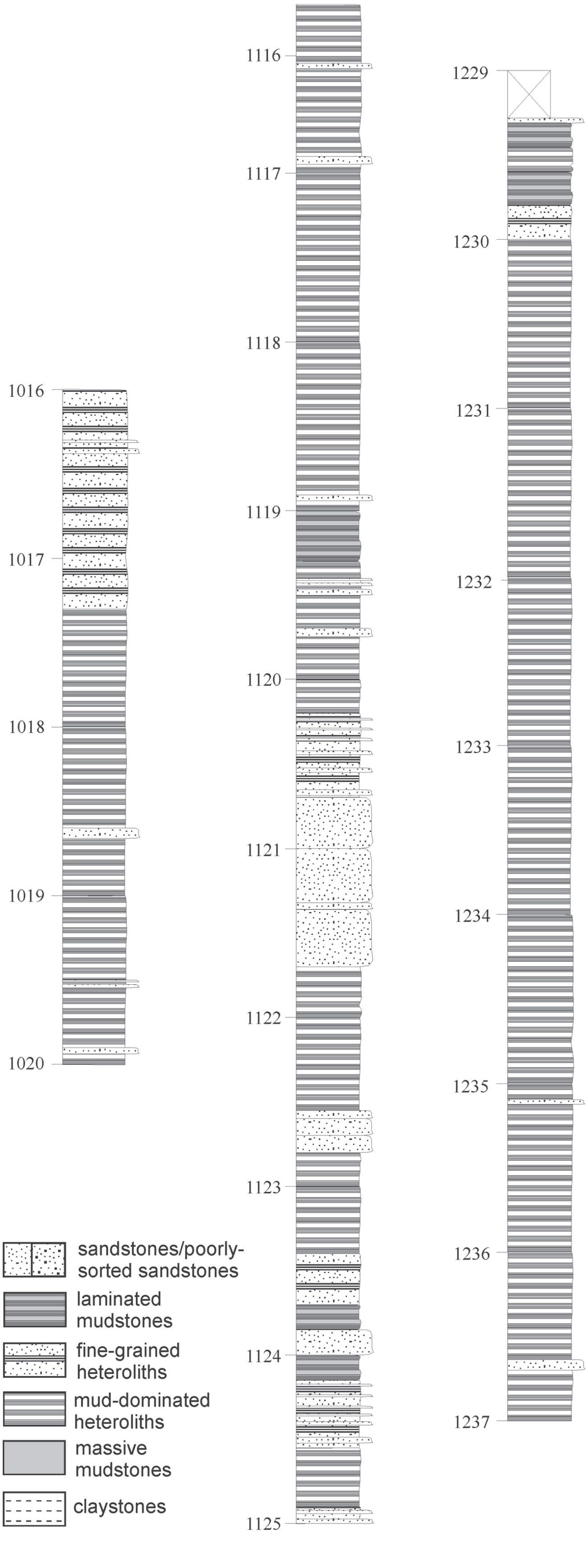


Fig. 7. Lithological log of the core material from the Stobierna 4 borehole.

In the Sokołów area the Badenian/Sarmatian boundary is largely conventional, and coincides with the first appearance of species *Anomalinoides dividens* (Łuczkowska 1964; Dziadzio et al. 2006), which can be roughly correlated with the upper part of the nannoplankton NN6 Zone (Marunteanu 1999; Kováč et al. 2006; Oszczypko-Clowes in Krzywiec et al. 2008).

The described core material is characterized by a monotonous lithology (Table 1, Figs. 5–9). Larger differences in lithology are visibly only on the graphs of well logging.

On this basis, Papiernik (in Krzywiec et al. 2008) distinguished four lithofacies: sandy-FPC (clays 0–25 %), sandy/clayey-FP/I (clays 25–50 %), clayey-sandy FI/P (clays 50–75 %) and clayey FI (clays more than 75 %).

On the basis of the description of the borehole cores the following lithofacies have been distinguished: hemipelagites, thin-bedded heteroliths, classical turbidites and thick-bedded sandstones (cf. Porebski & Warchoł 2006).

Hemipelagites (facies D2.3, Pickering et al. 1986) are represented by dark grey, marly, mudstones with discrete horizontal lamination. Bright laminas 1–2 mm thick are formed from fine particles of quartz and muscovite. Laminas a few millimeter thick composed of very fine-grained sand are rare. In mudstones fine crushed thin-skinned fauna are ofen observed. The thickness of mudstone intercalations are usually from 0.5 to 2–3 m. The thickest package of mudstone with a thickness of at least 9 m was found in the borehole Stobierna 3 (depth interval 715–724 m). These sediments were deposited by low-density suspension currents or weak bottom currents.

Thin-bedded heteroliths (D2.1, Pickering et al. 1986), usually intercalated by hemipelagites, are characterized by rhythmic intercalations of very thin-bedded sandstones, siltstones and mudstones. The sandstones display lenticular, stripped and wavy stratification. Muddy/sandy and sandy/muddy heteroliths can be distinguished in the studied cores. The muddy/sandy heteroliths are characterized by layer-cake of mudstones and very-fine sandstones with a thickness of 2 mm to 1.5–2.0 cm. The thicker laminas display low-angle diagonal lamination and small load-casts. In sandy/muddy heteroliths the thickness of thin layers of sandstone is greater than in the mudstone variety. At the top of sandstones, the accumulation of coalified plants is often observed. The heteroliths were deposited by low-density currents or bottom currents with suspension traction. *Classical turbidites* (C2.2–C2.3, Pickering et al. 1986) were uncommonly observed. Almost always they were layers of fine-grained sandstone about 10 cm thick. These sandstones are characterized by lime-muddy cement. The sandstones display typical Bouma sequence of stratification typical sequence: ripple cross lamination, convolution and the upper parallel lamination. The thicker sandstone layers (up to 15 cm) also contained turbidite Tbc + conv. The thin-bedded turbidites were deposited by low-density turbidite flows.

Thick-bedded sandstones (0.4–1.0 m) (B1.1, Pickering et al. 1986) are usually structureless, brittle and poorly-cemented, muscovitic, medium to fine-grained, with minor levels of muddy clasts. Sometimes the top of fine-grained sandstone is more strongly cemented than the basal part of beds. The sandstones were deposited by high-density suspension currents, by rapid mass deposition as a result of intergranular collisions.

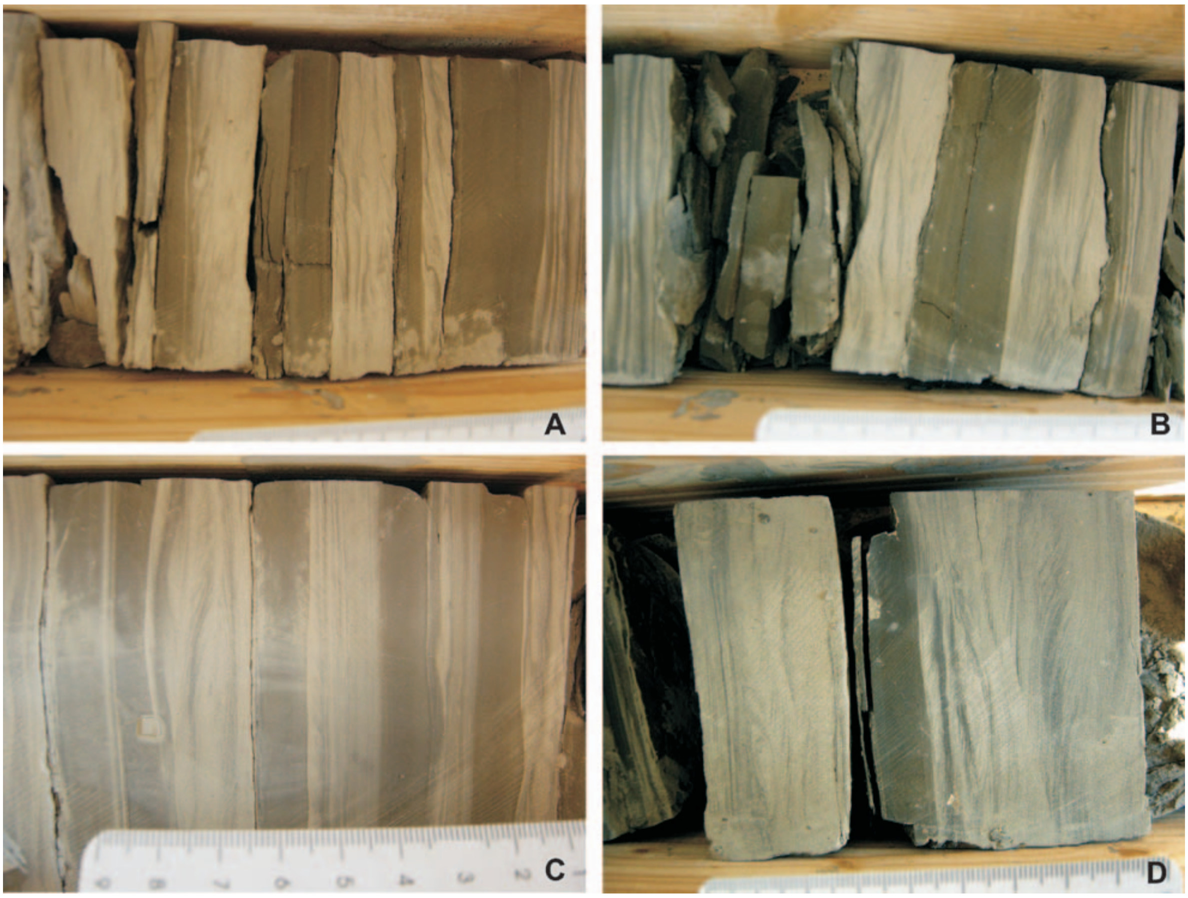


Fig. 8. Photographs of the core material from the Stobierna 4 borehole. Thin-bedded, layer-cake, muddy/silty/sandy heteroliths, with horizontal laminations: **A** — depth interval 1229–1238 IV; **B** — depth interval 1229–1238 V; **C** — depth interval 1229–1238 VI; **D** — depth interval 1229–1238 V. (A,B,C) and diagonal-stripped lamination.

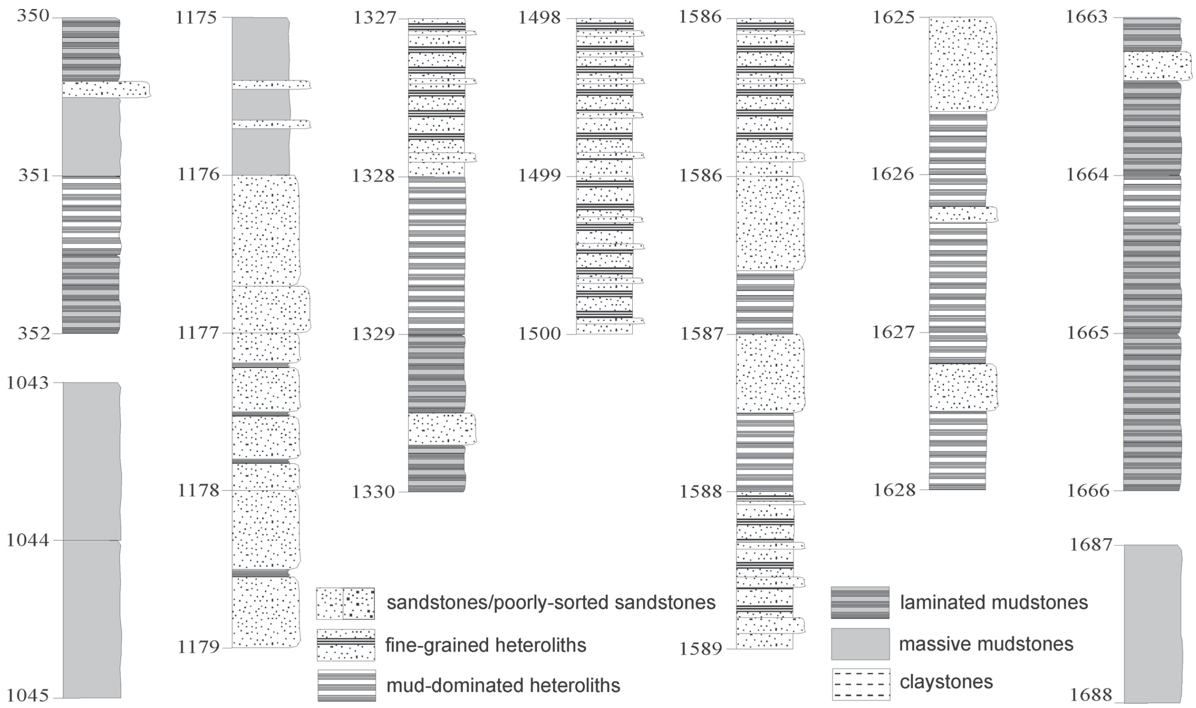


Fig. 9. Lithological log of the core material from the Stadnicka Brzóza borehole.

Table 1: Facies characteristic.

Depth [m]	Facies characteristic
	STOBIERNA 3
515 – 524 (1)	The laminated grey siltstone with intercalations of fine- to medium-grained muscovite, poorly cemented, massive medium (15 cm) to thick-bedded (50 cm) sandstones, with fragments of crushed fauna.
715 – 724 (2)	The dark grey, marly claystones and mudstones with discrete horizontal lamination, numerous small fragments od crushed fauna. (3 samples)
834 – 843 (3)	At the top 3 m thick packet thick-bedded (up 1.5 m) fine- to medium-grained, polimictic sandstones with fine muddy clasts. Below the grey sand-muddy heteroliths with intercalations, thin-bedded fine-grained, muscovite sandstones with horizontal and ripple-cross lamination. subordinate occur the medium to thick-bedded muscovitic sandstones (60 cm), with dispersed coalified plants, low-angle cross-lamination, dish-structure. (1 sample)
1113 – 1122 (4)	Grey muddy-sandy heteroliths with laminated mudstones.
1290 – 1299 (5)	Grey sandy-muddy heteroliths with intercalation of thin-bedded (to 10 cm), fine-grained turbidites (Tc+konv+d). (1 sample)
1660 – 1669 (6)	Muddy-sandy heteroliths. Mudstones with horizontal lamination, thin-bedded, very-fine-grained sandstones with horizontal and low-angle cross lamination, fine load casts.
1733 – 1737 (7)	Variegated (green and red) metaargilites (Lower Cambrian–Precambrian).
	STOBIERNA 4
1016 – 1021 (1)	Very thin-bedded (2–4 cm), very fine-grained, muscovitic sandstones. Mudstones with horizontal lamination, sandstones with horizontal and ripple cross-lamination. At the top of sandstones bed lenticular piritizidet coalified flakes.
1116 – 1125 (2)	Muddy-sandy heteroliths. Mudstones with horizontal lamination, fine-grained sandstones (up to 4 cm) with ripple-cross lamination. Number of lamines up to 3 mm with coalified, pyrititizid plants.
1229 – 1238 (3)	Muddy-sandy heteroliths. Mudstones with horizontal lamination; thin-bedded (0.5–3.5 cm), fine-grained, muscovitic sandstones with ripple cross-lamination.
	STADNICKA BRZÓZA 1
350 – 356 (1)	Muddy-sandy heteroliths.
1043 – 1047 (5)	Grey laminated mudstones, crushed. (1 sample)
1175 – 1179 (6)	Muddy-sandy heteroliths, crushed. In last box 10 cm fine-grained sandstone with intercalations of laminated mudstones. Sample 1.
1327 – 1331 (7)	Sandy-muddy heteroliths. Fine-grained, muscovitic sandstones, up to 5 cm thick, with coalified flakes. Low angle cross lamination.
1498 – 1502 (8)	Sandy-muddy heteroliths. Fine-grained, muscovitic sandstones, up to 5 cm thick, with coalified flakes. Low angle cross-lamination.
1586 – 1590 (9)	Sandy mudstones, laminatem, with intercalations fine- to medium-grained, muscovitic, thin to thick-bedded sandstones (up 60 cm), crushed sandstones with dispersed coalified flakes.
1625 – 1629 (10)	Fine-grained, thick-bedded (up 60 cm) sandstones with coalified flakes. Lower sandy-muddy heteroliths.
1663 – 1667 (11)	Muddy-sandy heteroliths with intercalations fine- and very fine-grained sandstones with horizontal lamination.
1687 – 1691 (12)	Metaargilites (Lower Cambrian–Precambrian).

Lithofacies described by us can be roughly correlated with those defined on the basis of well logging curves (Papiernik in Krzywiec et al. 2008): *hemipelagites* = clayey facies; *heteroliths and thin-bedded turbidites* = sandy/clay facies; thick-bedded sandstones = sandy facies (Figs. 5–9).

Material and methods

Our studies of the Machów Formation were concentrated in the eastern part of the PCFB, north of Rzeszów (Figs. 1, 2). In this area, 33 samples were collected from five boreholes at the following depth intervals: Stobierna 2 (S-2): 1016–1338 m (5 samples); Stobierna 3 (S-3): 715–1669 m (10 samples); Stobierna 4 (S-4): 1016–1238 m (7 samples); Stadnicka Brzóza 1 (SB-1): 350–356 m and 1043–1667 m (7 samples); Pogwizdów (P-2): 1161–1390 m (4 samples). The uppermost (above 350 m) and lowermost (beneath 1669 m) parts of the Machów Formation were not studied because of lack of core material.

All samples were prepared using the standard smear slide technique and analysed under light microscope Nikon Eclipse E600POL (LM, 1000× magnification) with parallel and crossed nicols. Several photographs of specimens taken in LM are presented in Figs. 10–13.

The qualitative and the quantitative analyses were carried out for all the samples. The traditional preparation technique enabled the estimation of the relative abundance determined by counting, when possible, up to 300 specimens in random fields of view. In order to analyse and calculate the percentage abundance of autochthonous and allochthonous assemblages the authors accepted the 5 % range error. The paleoecological analyses were performed on autochthonous assemblages. Abundances were calculated for individual species with an error range of 0 % — the total amount of autochthonous species in each of the slides is equal to 100 %. The calcareous nannofossil distribution (nominal values as well for all species and percentages only for the autochthonous species) in each borehole is listed in Appendix and electronic edition of Tables 3–7 included at www.geologicacarpathica.sk.

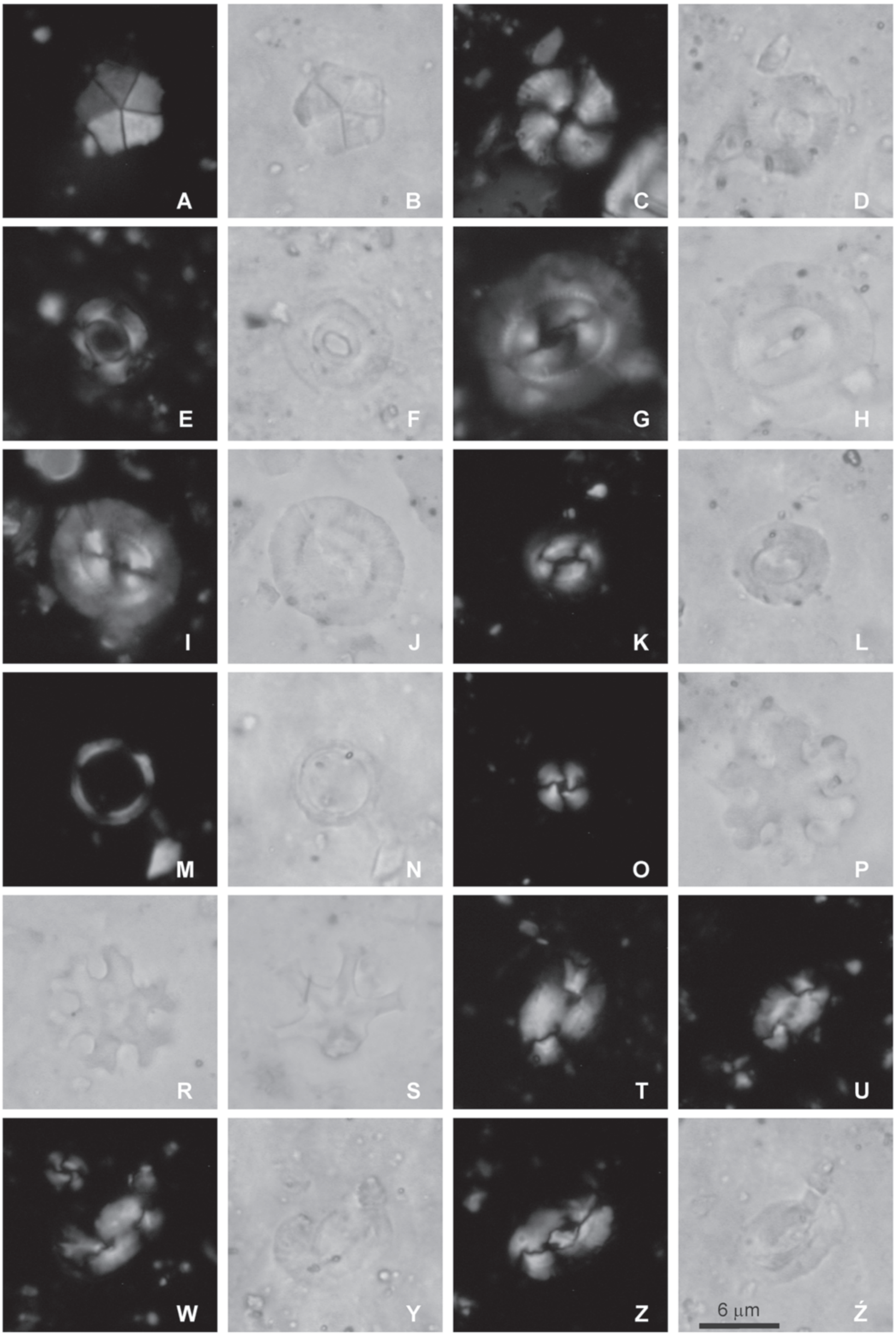


Fig. 10. LM microphotographs of the typical Miocene nannofossil assemblages. **A, B** — *Braarudosphaera bigelowii* (S-3 715-724 I); **C, D** — *Calcidiscus leptoporus* (S-3 715-724 I); **E, F** — *Calcidiscus premacintyrei* (S-3 715-724 IX); **G, H** — *Coccolithus miopelagicus* (S-3 715-724 I); **I, J** — *Coccolithus miopelagicus* (S-3 715-724II); **K, L** — *Coccolithus pelagicus* (S-3 715-724I); **M, N** — *Coronocyclus nitescens* (S-3 715-724 I); **O** — *Cyclicargolithus floridanus* (S-4 1229-1238 V); **P** — *Discoaster deflandrei* (S-4 1116-1125 I); **R** — *Discoaster deflandrei* (S-3 1113-1122 II); **S** — *Discoaster variabilis* (S-3 834-843 VIII); **T** — Helicosphaera *carteri* (S-3 715-724 IX); **U** — *Helicosphaera carteri* (S-4 1116-1125 I); **W, Y** — *Helicosphaera carteri* (S-4 1116-1125 I); **Z, Ź** — *Helicosphaera intermedia* (S-3 715-724 I).

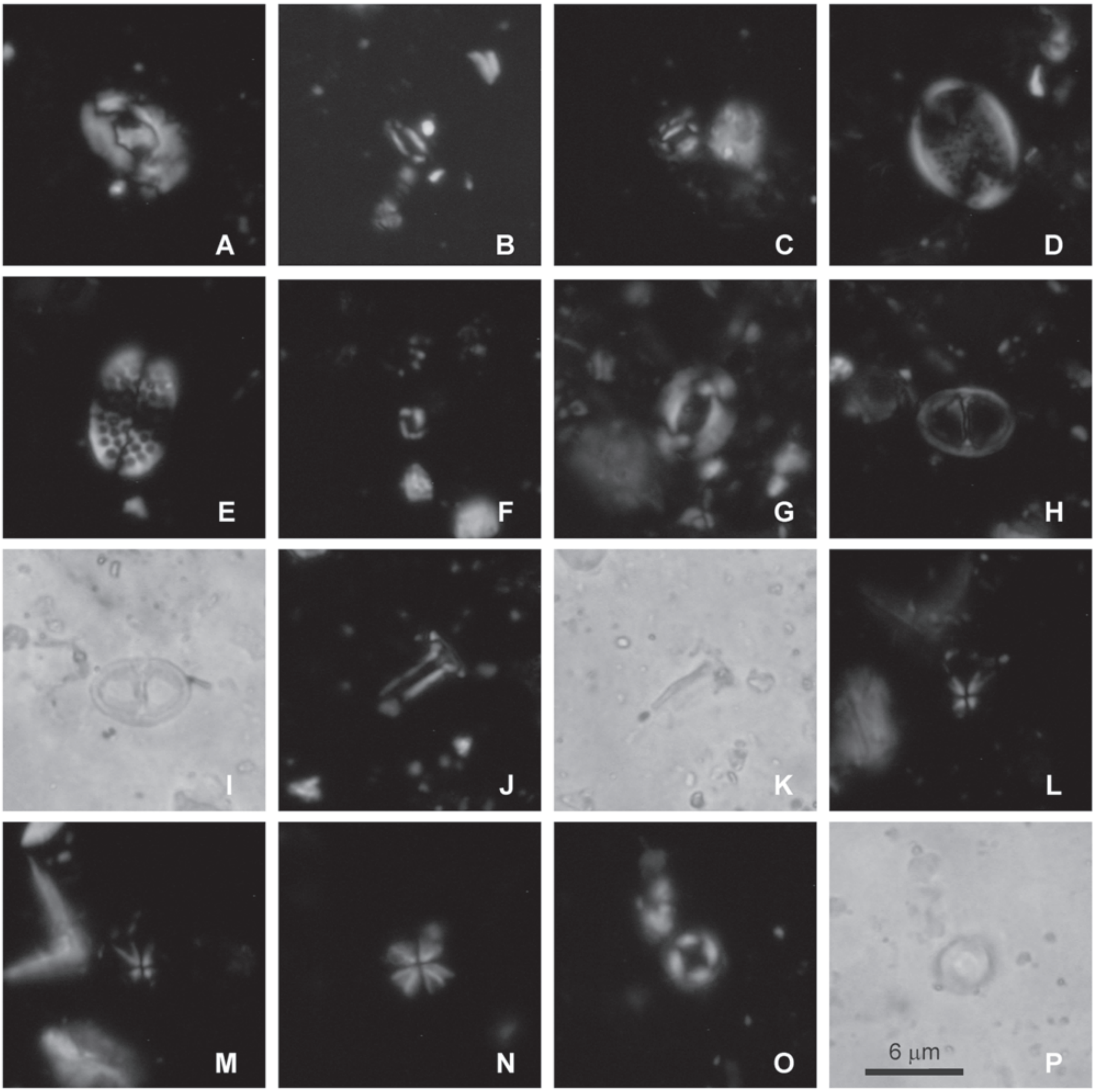


Fig. 11. LM microphotographs of the typical Miocene nannofossil assemblages. **A** — *Helicosphaera intermedia* (S-3 715–724 II); **B** — *Helicosphaera walbersdorfensis* (S-4 1229–1238 V); **C** — *Helicosphaera walbersdorfensis* (S-3 1113–1122 II); **D** — *Pontosphaera discopora* (S-4 1116–1125 IX); **E** — *Pontosphaera multipora* (S-4 1116–1125 IX); **F** — small *Reticulofenestra* (S-4 1116–1125 I); **G** — *Reticulofenestra pseudoumbilica* (S-4 1229–1238 VII); **H, I** — *Solidopons petrae* (S-3 715–724 II); **J, K** — *Rhabdosphaera clavigera* (S-3 834-843 IV); **L, M** — *Sphenolithus abies* (S-3 715–724 II); **N** — *Sphenolithus moriformis* (S-3 715–724 IX); **O, P** — *Umbilicosphaera rotula* (S-4 1116–1125 IX).

The relative abundance is a good indication of the general assemblage character, but rare sampling, due to available core material, makes paleoecological interpretation problematic. Another significant issue results from the large amount of redeposited material. In our work species with different stratigraphical range were included in the allochthonous group. Among the long-ranging taxa we cannot distinguish whether the specimen is autochthonous or not. The occurrence of taxa resistant to carbonate dissolution may also improve their relative frequencies. That may strongly affect the real abundance.

Results

Autochthonous versus reworked nannofossils — assemblages description

The majority of the examined samples yielded abundant and relatively well preserved assemblages. Some taxa were medium well or poorly preserved in the form of small fragments or with broken elements what made identification questionable. Traces of specimen dissolution were not ob-

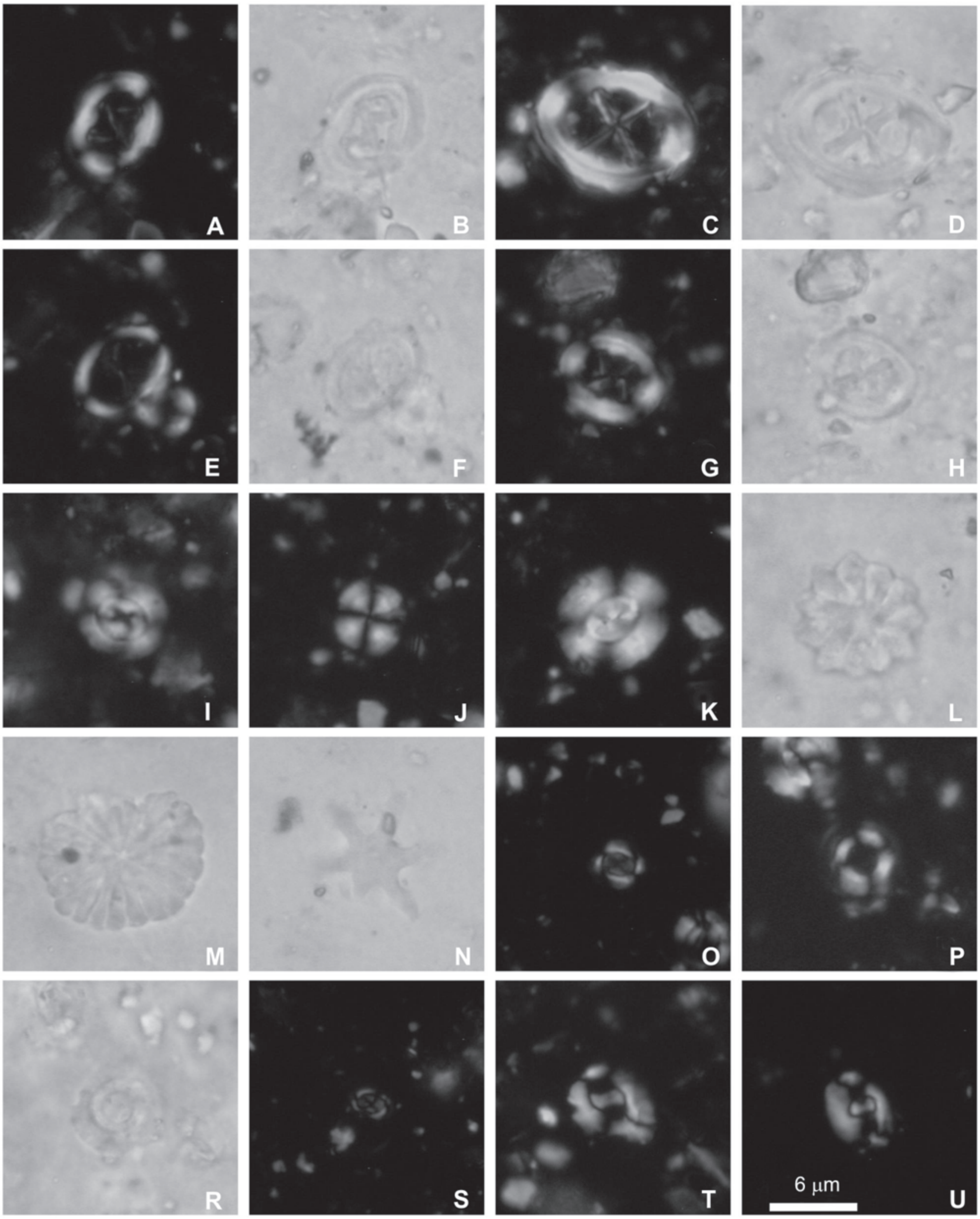


Fig. 12. LM microphotographs of the typical reworked nannofossil assemblages. **A, B** — *Chiasmolithus bidens* (S-3 715-724 VIII); **C, D** — *Chiasmolithus modestus* (S-4 1016-1021 II); **E, F** — *Chiasmolithus oamaruensis* (S-3 834-843 VIII); **G, H** — *Chiasmolithus solitus* (S-4 1229-1238 VII); **I** — *Cyclicargolithus abisectus* (S-3 715-724 I); **J** — *Cyclicargolithus luminis* (S-3 715-724 IX); **K** — *Dictyococcites bisectus* (S-4 1016-1021 II); **L** — *Discoaster barbadiensis* (S-3 715-724 I); **M** — *Discoaster multiradiatus* (S-3 834-843 VIII); **N** — *Discoaster tanii nodifer* (S-3 715-724 IX); **O** — *Ericsonia fenestrata* (S-3 834-843 VIII); **P, R** — *Ericsonia formosa* (S-4 1229-1238 V); **S** — *Ericsonia subdisticha* (S-4 1016-1021 II); **T** — *Helicosphaera bramlettei* (S-3 715-724 IX); **U** — *Helicosphaera bramlettei* (S-3 715-724 IX).

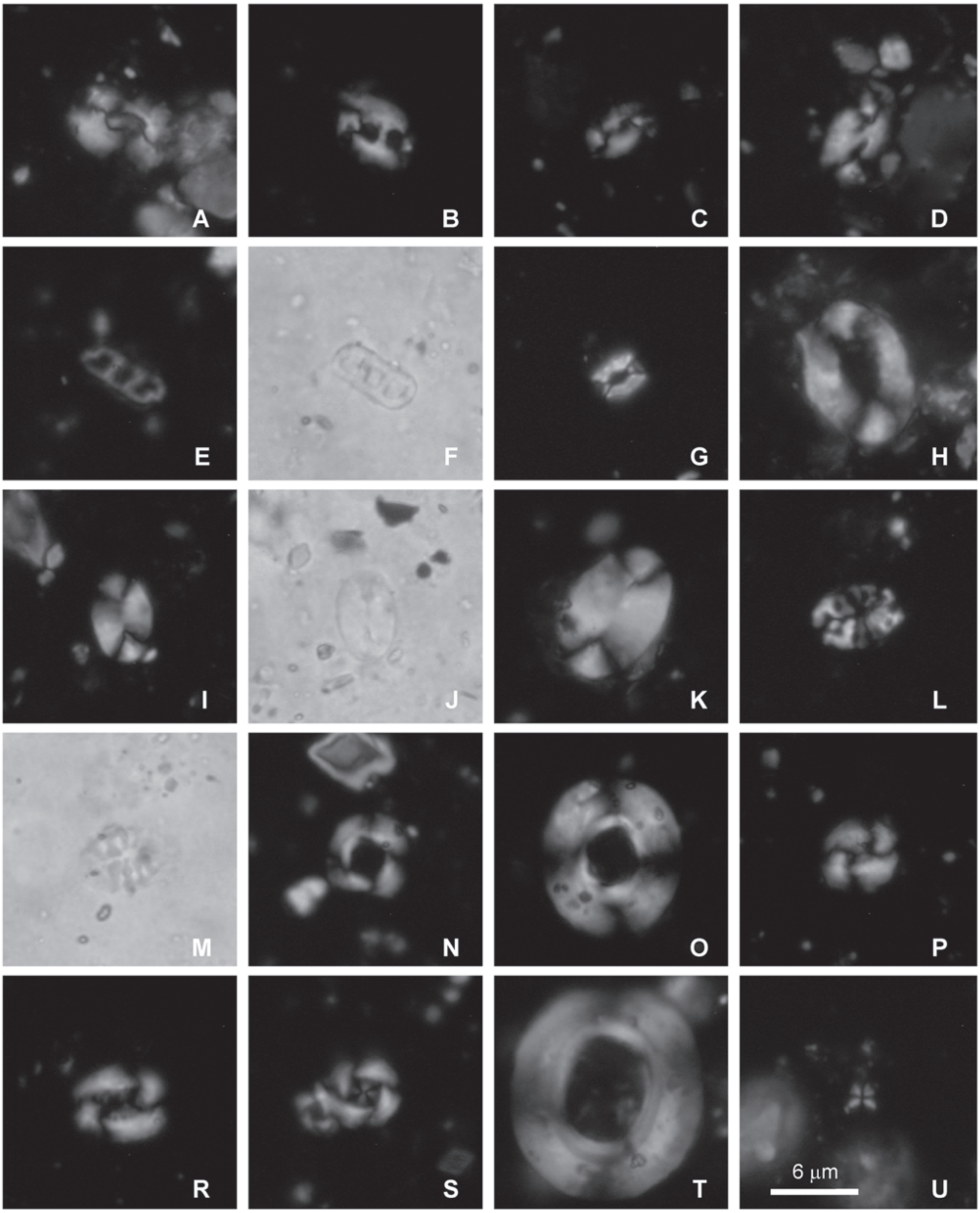


Fig. 13. Typical, reworked nannofossil assemblages. **A** — *Helicosphaera euphratis* (S-3 715-724 I); **B** — *Helicosphaera recta* (S-3 1113-1122 II); **C** — *Helicosphaera perch-nilseniae* (S-3 715-724 I); **D** — *Helicosphaera waltrans* (S-3 715-724 IX); **E, F** — *Isthmolithus recurvus* (S-3 834-843 IV); **G** — *Lanternithus minutus* (S-4 1116-1125 IX); **H** — *Pontosphaera latelliptica* (S-4 1116-1125 IX); **I, J** — *Pontosphaera plana* (S-3 715-724 I); **K** — *Pontosphaera plana* (S-4 1229-1238 VII); **L, M** — *Pontosphaera rothi* (S-3 715-724 IX); **N** — *Reticulofenestra dictyoda* (S-4 1229-1238 V); **O** — *Reticulofenestra hillae* (S-3 715-724 IX); P — *Reticulofenestra lockerii* (S-4 1229-1238 VIII); **R** — *Reticulofenestra ornata* (S-4 1229-1238 VII); **S** — *Reticulofenestra reticulata* (S-4 1229-1238 V); **T** — *Reticulofenestra umbilica* (S-3 834-843 IV); **U** — *Sphenolithus conicus* (S-3 834-843 VIII).

served. Only 3 samples from S-3 (1660–1669 VI, 1660–1669 II and 1290–1295 II) and 2 samples from S-4 (1229–1238 VII and 1116–1125 IV) revealed relatively lower quantities of specimens which resulted in their total number under 300. These variations in the abundances could be associated with volumetric differences in the amount of sampled material. In the case of poor sampling, the odds of finding rare species is thus reduced.

For each sample the autochthonous/reworked nannofossils ratio was estimated (Fig. 14). The autochthonous assemblages in each examined borehole, as mentioned above, were accompanied by frequently occurring reworked nannofossils of Cretaceous, Paleogene and Early Miocene age. The percentage of allochthonous assemblages oscilates between 40 and 60 % and could be even higher due to unseparated long-living forms (e.g. *Coccolithus pelagicus*, *Cyclicargolithus floridanus*).

The distribution patterns of autochthonous nannofossils are illustrated in electronic edition of Tables 3–7 included at www.geologicacarpathica.sk.

The Miocene association in **S-2** is formed by abundant occurrences of *Coccolithus pelagicus* and *Cyclicargolithus floridanus* and relatively common *Helicosphaera carteri*, *Sphenolithus moriformis*, *Reticulofenestra pseudoumbilica* and small reticulofenestrids. Assemblages are also characterized by the frequent presence of: *Pontosphaera discopora*, *Pontosphaera multipora*, *Coccolithus miopelagicus*, *Helicosphaera walbersdorfensis*, *Coronocyclus nitescens*, *Sphenolithus abies* and *Umbilicosphaera rotula*. Sporadic specimens were observed of *Braarudosphaera bigelowii*, *Calcidiscus leptoporus*, *Calcidiscus macintyrei*, *Calcidiscus premacintyrei*, *Discoaster variabilis*, *Discoaster exilis*, *Helicosphaera intermedia* and *Helicosphaera stalis.*

The nannoplankton assemblage from **S-3**, similarly to S-2, is mostly represented by species such as *C. pelagicus* and *Cy. floridanus*, *H. carteri*, *S. moriformis*, *R. pseudoumbilica,* small reticulofenestrids. The following were also observed with relatively high frequency: *P. multipora*, *S. abies*, *U. rotula*, *C. nitescens*, *C. miopelagicus*, *H. walbersdorfensis*, *P. discopora*, *H. intermedia* and *Cd. leptoporus* in the upper part of the profile (from 715–724 VIII). From 834–843 VIII common occurrences of *C. miopelagicus* >10 μm were noticed. Such species as *B. bigelowii* and *Cd. premacintyrei* were present in lower numbers. *Discoaster variabilis* and *D. deflandrei* were recognized only in a few samples. In three samples from the lower part of the profile (1660–1669 VI, 1660–1669 II, 1290–1295 II) with a lower quantity of specimens, high numbers of *C. pelagicus* and *Cy. floridanus* were observed.

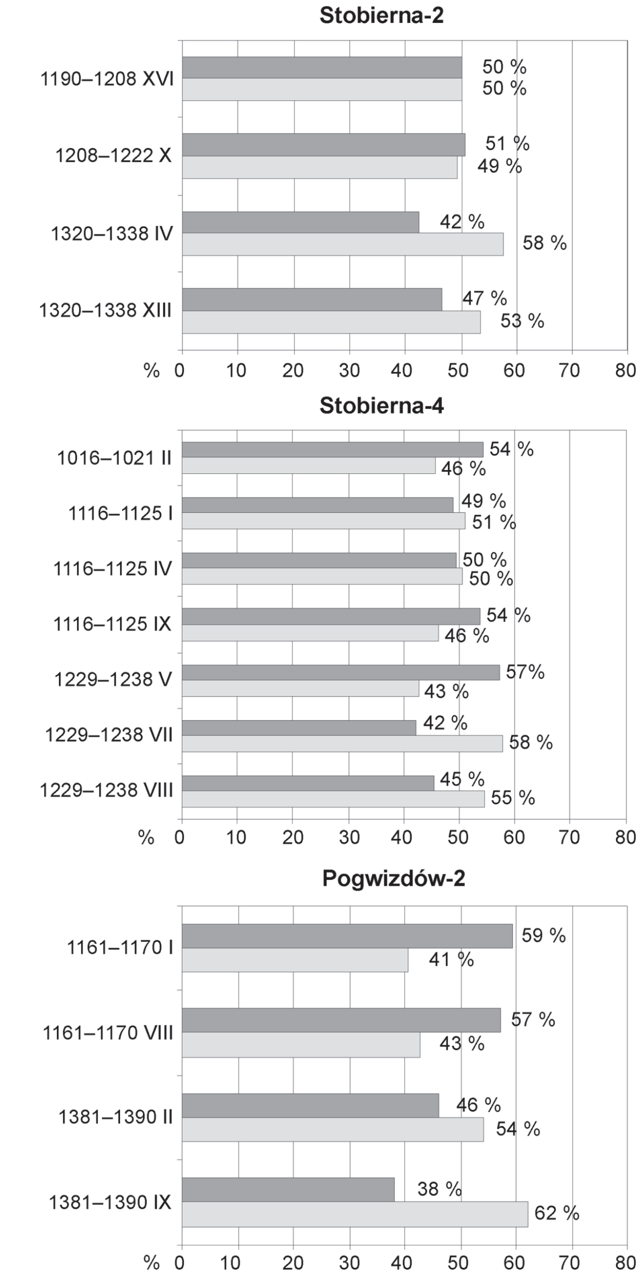
In **S-4** the assemblage is also characterized by common presence of species such as: *C. pelagicus* and *Cy. floridanus*, *H. carteri*, *S. moriformis* and small reticulofenestrids. The following also frequently occurred: *P. multipora*, *S. abies*, *U. rotula*, *P. discopora*, *C. nitescens*, *C. miopelagicus*, *H. walbersdorfensis*, *R. pseudoumbilica*, *H. intermedia*, *B. bigelowii* and *Cd. leptoporus.* Irregularly occurring specimens of *Cd. premacintyrei* and *Rhabdosphaera clavigera* were recognized only in 2 samples from the upper part of the profile (1116–1125 I, 1016–1016–1021 II). In sample 1116–1125 I with a total number of specimens under 300, the similar disproportion of species percentage was noticed — common species such as *C. pelagicus* and *Cy. floridanus* quantitatively prevails over the other species.

Within the assemblage from **SB-1**, *C. pelagicus* and *Cy. floridanus* occurred with explicit dominance over the other species. Species such as *H. carteri*, small reticulofenestrids, *S. moriformis*, *R. pseudoumbilica*, *P. multipora*, *P. discopora*, *H. walbersdorfensis*, *C. nitescens*, and *C. miopelagicus* were observed frequently. *U. rotula*, *S. abies*, *D. deflandrei* were noticed in lower numbers. Specimens of *B. bigelowii*, *Cd. premacintyrei*, *D. variabilis*, *D. exilis*, *H. stalis*, *H. intermedia*, *Triquetrorhabdulus rugosus*, *R. clavigera* and *Holodiscolithus macroporus* were recognized sporadically. In one sample from the uppermost of the profile 350–356 I a few specimens of *C. miopelagicus* >10 μm and *D. challengeri* were identified.

In **P-2** the assemblage mostly consisted of *C. pelagicus* and *C. floridanus*. Such species as small reticulofenestrids, *S. moriformis*, *H. carteri*, *H. walbersdorfensis*, *P. multipora*, *P. discopora*, *R. pseudoumbilica* and *C. nitescens* with relatively high occurrence were noticed. Specimens of *B. bigelowii*, *Cd. leptoporus*, *C. miopelagicus*, *D. deflandrei*, *H. stalis*, *H. intermedia*, *H. macroporus*, *U. rotula*, *Cd. premacintyrei* and *S. abies* occur irregularly. *Cd. macintyrei*, *R. clavigera*, *D. variabilis* and *T. rugosus* were observed sporadically.

Biostratigraphy

The standard Miocene nannofossil zonation was constructed mainly on the basis of the *Discoasteraceae* representatives. Distribution of this group is presumably controlled ecologically and depends on paleogeography. Therefore this Miocene subdivision is easily accomplished in low latitudes where discoasters are common in the open oceanic nannoplankton assemblages (Perch-Nielsen 1985). It is problematic in high latitudes, due to their absence or rare occurrence, and in marginal marine assemblages where discoasters and other markers occur sporadically (Perch-Nielsen 1985). This also applies to other index species, which commonly occur only at lower latitudes. Therefore, the Miocene zonations of Martini & Worsley (1970) and Bukry & Okada (1980) work best for areas from low latitudes. Given the Miocene paleobiogeographical and paleoecological diversity of calcareous nannoplankton, a number of regional divisions modifying previously formed zonations were proposed (Roth et al. 1971; Műller 1978; Raffi & Rio 1979; Theodoridis 1984; Raffi et al. 1995; Fornaciari & Rio 1996; Fornaciari et al. 1996; Young 1998; Švábenická 2002 and Ćorić & Švábenická 2004). According to Báldi-Beke (1982) helicoliths are neither strictly oceanic nor typical nearshore nannofossils (see Švábenická 2002). This fact resulted in their expansion in unstable paleoecological conditions in the Carpathian Foredeep and hence in increase of their biostratigraphical significance (Švábenická 2002). The composition of nannoplankton assemblages from Stobierna 2, Stobierna 3, Stobierna 4, Pogwizdów 2 and Stadnicka Brzóza 1 boreholes allowed authors to establish the presence of Zones NN6 and NN7. The detailed description of these zones is given below.



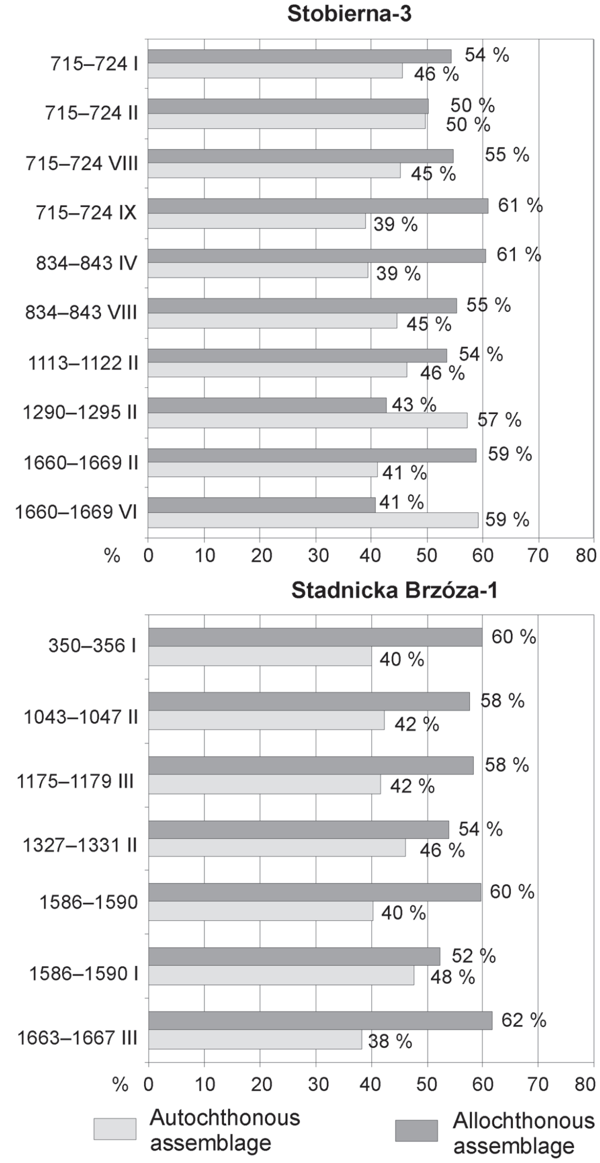


Fig. 14. Percentage abundance of autochthonous and allochthonous (reworked) species in samples from the Stobierna 2, Stobierna 3, Stobierna 4, Pogwizdów 2, Stadnicka Brzóza 1 boreholes.

Discoaster exilis Zone (NN6)

Discoaster exilis zone assignment is based on the presence of *Reticulofenestra pseudoumbilica*, *Sphenolithus abies*, *Helicosphaera stalis*, *Helicosphaera walbersdorfensis* and absence of species such as *Sphenolithus heteromorphus* and *Discoaster kugleri*. From biostratigraphical point of view the stratigraphic range of *Helicosphaera walbersdorfensis* is significant. Its first appearance occurs in the highest part of NN5 and the last occurrence is near the NN6/NN7 boundary (Fornaciari et al. 1996; Young 1998, see also Dudziak & Łaptaś 1991). Müller (1981) was the first who noticed the utility of that species in Miocene biostratigraphy for the NN6 Zone. In addition the presence of *Cyclicargolithus floridanus* is important due to its last common occurrence taking place in the middle part of the NN7 Zone with an age of 13.33 Ma, (Gradstein et al. 2004). In most samples bigger specimens of *Reticulofenestra pseudoumbilica* were observed, as is characteristic for the NN6 Zone (cf. Fornaciari & Rio 1996). The smaller representatives of *Reticulofenestra pseudoumbilica* were already recognized in the NN2 Zone (Marunteanu 1992, see also Oszczypko-Clowes 2001; Holcová 2005). Moreover, *Sphenolithus abies* and *Helicosphaera stalis* are very significant species characteristic for the higher part of NN6 (cf. Young 1998). In all profiles, besides these above-mentioned species, there are frequent occurrences of such species as *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Helicosphaera carteri*, *Sphenolithus moriformis* and *Umbilicosphaera rotula*, what is also characteristic for NN6 Zone. Sporadic *Calcidiscus leptoporus* and *Calcidiscus* *premacintyrei* were observed. The estimated age for the top regular occurrence of *Cd. premacintyrei* is 12.45 Ma (Gradstein et al. 2004). According to the standard zonation (Martini 1971) the LO of *Sphenolithus heteromorphus* marks the NN5/NN6 boundary. It is important to notice the fact that these species were observed in the samples. However, taking into account the presence of *Sphenolithus abies*, *Helicosphaera stalis* and *Coronocyclus nitescens,* it is possible to assume that the presence of *Sphenolithus heteromorphus* is due to reworking. The age of the top occurrence of *C. nitescens* is 12.45 Ma (Gradstein et al. 2004).

Discoaster kugleri Zone (NN7)

The *Discoaster kugleri* Zone (NN7) is usually defined by the first occurrence of *Discoaster kugleri* (Martini 1971; Bukry & Okada 1980) to the first occurrence of *Catinaster coalitus*. It is worth noting that in borehole Stobierna 3 (depth 715–724 m) and Stadnicka Brzóza 1 (depth 350–356 m) the first appearance of *Calcidiscus macintyrei* and *Coccolithus miopelagicus* (> 14 μm) takes place. Many researchers suggest using alternative indicators, such as the last common occurrence of *Calcidiscus premacintyrei*, which takes place just before the first occurrence of *Discoaster kugleri* (Fornaciari et al. 1996) or the last occurrence of *Coronocyclus nitescens* and *Calcidiscus premacintyrei* (Raffi et al. 1995). This is because of the absence or scarce abundance of the index species, especially *Discoaster kugleri*. It regards especially high latitude areas, where discoasters or *Catinaster coalitus* are practically uncommon. That is the reason why assignment of the NN7 Zone was based mainly on large specimens of *Coccolithus miopelagicus* (> 14 μm) and *Calcidiscus macintyrei*. The age of the top occurrence of *Cd. macintyrei* is estimated as 14.46 Ma (Gradstein et al. 2004). Presence of *Coccolithus miopelagicus* (> 14 μm) is essentially confined just to that interval, but its first occurrence is gradational (Young 1998). The first appearance of *Calcidiscus macintyrei* is a controversional issue. According to Fornaciari et al. (1996) and Young (1998), it takes place near the NN6/NN7 boundary. However Švábenická (2002) and Ćorić & Švábenická (2004) describe this species as early as from the NN6 and even from NN5 Zone. Specimens of *Catinaster coalitus* were not observed. The percentage of *Cyclicargolithus floridanus* gradually decreases, what also could indicate NN7 Zone. *Discoaster deflandrei* occurs occasionally, which is typical for this interval. *Discoaster deflandrei* becomes very rare and disappears near the top of this zone (Perch-Nielsen 1985). Likewise *Calcidiscus premacintyrei* occurs rarely, and its last occurrence is established as the indicator of the NN7 Zone.

Table 2: Percent abundance of main paleoecological groups.

	Temperature				Trophism		
	Warm-water species	Moderate species	Cold-water species	Others	Eutrophic species	Oligotrophic species	Others
Stobierna 2							
1190–1208 I	36	5	47	12	57	36	7
1190–1208 XVI	22	19	52	7	58	37	5
1208–1222 X	24	12	54	9	60	32	7
1320–1338 IV	20	5	73	3	74	22	4
1320–1338 XIII	25	19	50	6	54	38	8
Stobierna 3							
715–724 I	45	20	19	17	33	47	20
715–724 II	42	23	18	17	30	52	19
715–724 VIII	39	18	27	16	38	44	18
715–724 IX	37	18	34	11	41	49	10
834–843 IV	52	5	32	11	41	42	18
834–843 VIII	36	10	36	18	49	43	9
1113–1122 II	29	14	31	24	45	40	13
1290–1295 II	17	8	49	25	53	22	23
1660–1669 II	25	12	49	14	66	36	5
1660–1669 VI	14	10	65	11	70	19	11
Stobierna 4							
1016–1021 II	35	20	20	25	35	45	20
1116–1125 I	33	26	17	24	32	49	19
1116–1125 IV	20	11	60	9	64	30	6
1116–1125 IX	34	15	28	23	39	39	22
1229–1238 V	26	25	25	24	32	47	21
1229–1238 VII	33	17	31	19	40	42	19
1229–1238 VIII	37	15	24	24	34	43	23
Stadnicka Brzóza 1							
350–356 I	26	9	55	10	64	31	5
1043–1047 II	29	13	43	15	54	31	15
1175–1179 III	24	2	63	10	68	18	14
1327–1331 II	17	11	65	7	70	22	7
1586–1590	13	11	70	18	72	22	13
1586– 1590 I	17	10	55	7	64	23	6
1663–1667 III	11	21	50	17	63	30	7
Pogwizdów 2							
1161–1170 I	24	10	50	18	57	30	14
1161–1170 VIII	21	12	52	17	63	31	5
1381–1390 II	12	7	68	14	72	17	11
1381–1390 IX	15	14	61	12	62	17	20

Paleoecology

The paleoecological analysis of the Machów Formation was carried out on the basis of quantitative data of autochthonous assemblages in S-2, S-3, S-4, SB-1 and P-2. Paleoecological nannoplankton preferences were considered with regard to temperature and nutrient availability (Table 2). According to the way of sampling, restricted to particular intervals, the assemblage descriptions are divided into three parts (Figs. 15, 16). The first considers the depth between 1700 and 1550 m, the second from 1400 to 1000 m and the last the depth between 850 and 700 m (Figs. 15, 16).

Temperature. According to Andreyeva-Grigorovich (2002) the Late Badenian and Early Sarmatian calcareous

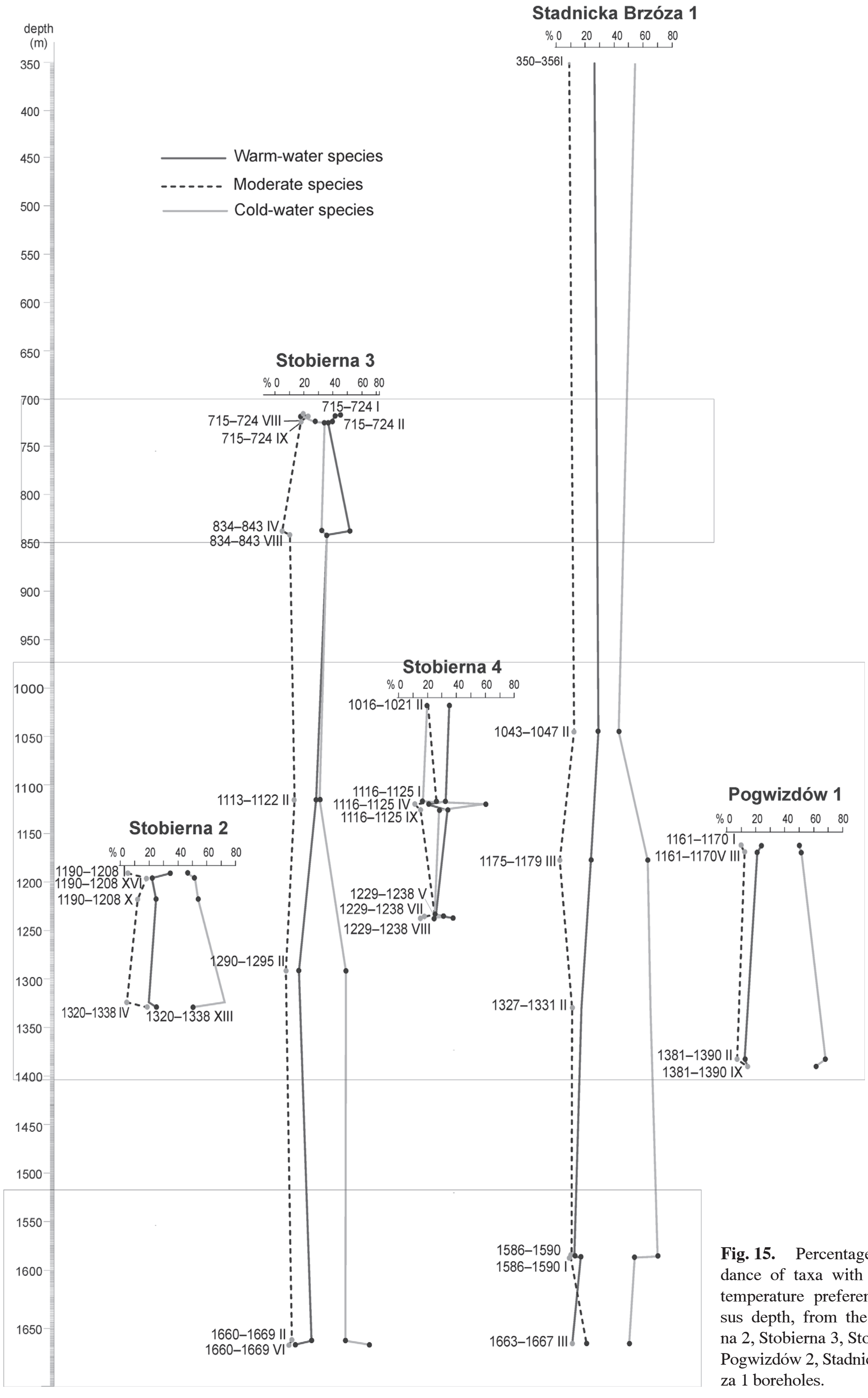


Fig. 15. Percentage abundance of taxa with different temperature preferences versus depth, from the Stobierna 2, Stobierna 3, Stobierna 4, Pogwizdów 2, Stadnicka Brzóza 1 boreholes.

nannofossils were divided into 7 ecogroups depending on temperature preferences: the groups of tropical and subtropical species (I — *Sphenolithus*, II — *Discoaster*, III — *Braarudosphaera)*, groups of moderate species (IV — *Calcidiscus*, V — *Helicosphaera)* and groups of cold-water species (VI–VII — *Coccolithus* + *Reticulofenestra*). Among the recognized assemblages the warm-water species group was represented by *B. bigelowii*, *C. miopelagicus*, *D. challengeri*, *D. deflandrei*, *D. exilis*, *D. variabilis*, *S. abies*, *S. moriformis* and small reticulofenestrids. The moderate species group consisted of such species as *Cd. leptoporus*, *Cd. macintyrei*, *Cd. premacintyrei*, *H. carteri*, *H. intermedia*, *H. stalis*, *H. walbersdorfensis.* The cold-water species group includes: *C. pelagicus*, *Cy. floridanus*, and *R. pseudoumbilica.*

At the depth **1700–1550 m,** samples were collected from the S-3 and SB-1 boreholes. In the S-3 borehole (samples 1660–1669 VI and 1660–1669 II) the assemblages are dominated by cold-water species over the moderate and warm-water species. The percentage abundance of cold-water species is up to 65 % and 49 % respectively. Similarly in SB-1, in samples from the lowermost part of the profile: 1663–1667 III, 1586–1590 I, 1586–1590, cold-water species are predominant (50 %, 55 %, 70 % respectively) (Table 2, Fig. 15).

At the second depth interval, **1400–1000 m**, samples from each profile were analysed (Table 2, Fig. 15). In P-2 at the depth 1381–1390 m, from IXth and IInd meter, paleoecological groups are characterized by dominance of cold-water species participation (61 and 68 %), whereas warm-water and moderate species percentages are comparable and do not exceed 15 %. A similar situation is found in SB-1 at the depth 1327–1331 II. Cold-water species occur with high abundance reaching up to 65 %. In the S-2 borehole, in samples collected from the interval 1320–1338 m, XIIIth and IVth meter, likewise in S-3 at the depth 1290–1295 II, the percentage of cold-water species is prevailing (50 %, 73 % and 49 % respectively), whereas the warm-water species group is more abundant than the moderate-water species. In S-4 in samples collected from the interval 1229–1238 m, from VIIIth, VIIth and Vth meter, differences between percentage abundance of cold- and warm-water species are not significant. The temperate water species group is slightly less numerous in the lower part of the profile, but in the upper part it equals the others in frequency. In S-2 in samples from 1208–1222 X, 1190–1208 XVI and 1190–1208 I, cold-water species abundance oscillates around 50 % in the whole autochthonous assemblage, whereas warm-water species prevail over moderate ones. In SB-1 at the depth 1175–1179 III, cold-water species are still predominant (63 %), temperate reaching not more than 2 %. In P-2 at 1161–1170 m, from the VIIIth and Ist meter, cold-water species percentage is around 50 %, whereas the contribution of warm-water species is twice as much as temperate. In S-4 at the depth 1116–1125 I, at the Xth, IVth and Ist meter, some variations were noticed. In the sample from the IXth meter warm-water species slightly prevail over cold ones, whereas at the IVth meter the percentage of cold-water species increased to 60 %. At the Ist meter warm-water species abundance increased to 33 % and temperate (26 %) prevail over cold ones (17 %). In S-3 in sample 1113–1122 II the cold-water/warm-water species ratio is 31 to 29 %, with lower frequency of moderate species (14 %). In SB-1 in the sample collected from 1043–1047 II, cold-water species prevail over the warm group (43 % to 29 %). In S-4 in sample 1016–1021 II, warm-water species participation is 35 %, whereas cold ones is 20 %, likewise moderate — 20 % (Table 2, Fig. 15).

The last depth interval between **850 and 700 m** was sampled only in S-3 (Table 2, Fig. 15). At the depth 834–843 VIII, warm- and cold-water species participations both reach 36 % (moderate — 10 %). In the same interval, but from IVth meter warm-water species substantially prevail over the cold-water (32 %) and moderate (5 %) ones. In samples 715–724 IX and 715–724 VIII the difference between participation of the cold- and warm-water groups is not significant. In the upper part of the profile, in samples 715–724 II and 715–724 I, predominance of warm-water species group was noticed with its participation twice as much as cold ones.

Trophic resources. With regard to nutrient availability, two paleoecological groups were distinguished among the autochthonous assemblages: species preferring eutrophic and species preferring oligotrophic conditions (Wei & Wise 1990; Aubry 1992; Krhovský et al. 1992). The following species were assigned to the former group: *B. bigelowii*, *C. pelagicus*, *Cy. floridanus*, *P. discopora*, *P. multipora* and *R. pseudoumbilica.* The latter group includes species such as *D. challengeri*, *D. deflandrei*, *D. exilis*, *D. variabilis*, *H. carteri*, *H. intermedia*, *H. stalis*, *H. walbersdorfensis*, *S. abies*, *S. moriformis* and small reticulofenestrids.

In the first analysed interval between **1700** and **1550 m** eutrophic species occurring with high frequency, prevail over oligotrophic species (Table 2, Fig. 16). In S-3 at the depth 1320–1338 XIII abundance of eutrophic species reached up to 70 %, whereas the oligotrophic group constituted 19 %. At the IInd meter the percentage of oligotrophic species increased to 36 % with constant predominance of eutrophic ones (66 %). A similar situation was noticed in SB-1 at the depth 1663–1667 III, 1586–1590 I, 1586–1590. The abundance of eutrophic species is within the range 63–72 %.

At the second depth (Table 2, Fig. 16) interval, **1400–1000 m,** in the P-2 borehole, eutrophic species abundance reached up to 62 and 72 % at the depth 1381–1390 m, at IXth and IInd meter respectively. In the SB-1 borehole at the depth 1327–1331 II the percentage of eutrophic species is around 70 %. In S-2 in the sample from interval 1320–1338 m, collected from XIIIth meter, the abundance of eutrophic species is 54 %, with 38 % oligotrophic ones. At the IVth meter in this interval, the percentage of eutrophic species increased to 74 %. In S-3 at the depth 1290–1295 II the percentage of eutrophic species reached up to 53 %, whereas oligotrophic ones is 22 %. In S-4 at the interval 1229–1238, within three analysed samples at the VIIIth meter, oligotrophic species slightly prevail over eutrophic group (43 to 34 % respectively). At the VIIth meter the percentage of both group oscillates around 40 %, and then at the Vth meter oligotrophic species abundance increased to 47 % whereas eutrophic ones is 32 %. In S-2 in samples from the depth 1208–1222 X, 1190–1208 XVI and 1190–1208 I, the percentage of eutrophic species prevails over oligotrophic and varies from 57–60 %. In SB-1 at the depth 1175–1179 III, eutrophic species abundance is 68 %, whereas oligotrophic is 18 %. In P-2

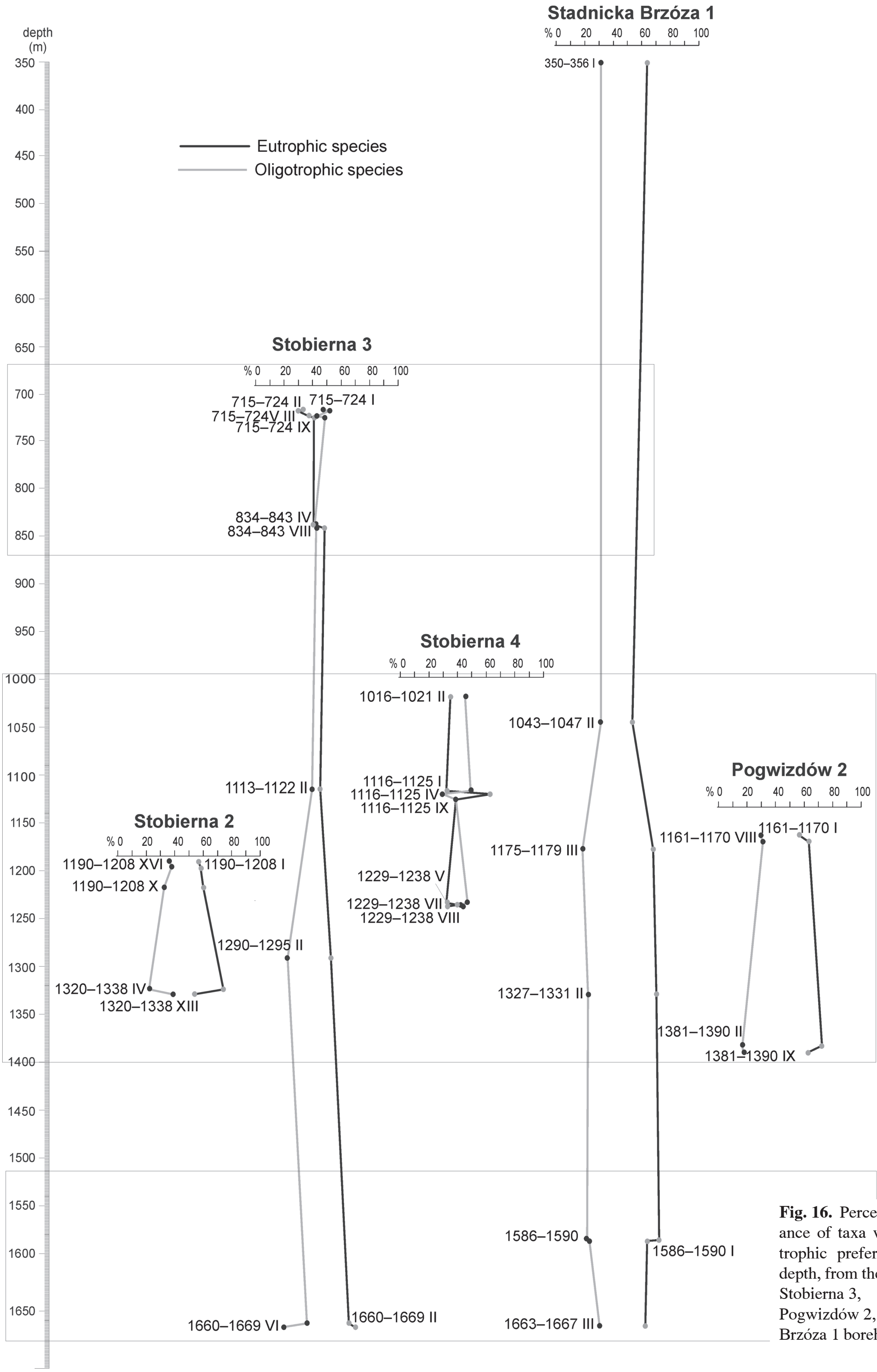


Fig. 16. Percentage abundance of taxa with different trophic preferences versus depth, from the Stobierna 2, Stobierna 3, Stobierna 4, Pogwizdów 2, Stadnicka Brzóza 1 boreholes.

at the interval 1161–1170 m, in samples collected from VIIIth and Ist meter, oligotrophic species percentage is around 30 %, whereas eutrophic ones amount respectively to 63 and 57 %. In S-4 at the depth 1116–1125 I, at the Xth, IVth and Ist meter, fluctuations were observed. In the lower part the percentage of both groups is the same (39 %), whereas at the IVth meter the percentage of eutrophic species is twice as much as the oligotrophic ones (64 to 30 % respectively). At the Ist meter abundance of oligotrophic species is higher than eutrophic ones (49 to 32 %). Likewise in S-3 in the sample from the depth 1113–1122 II oligotrophic species prevail over eutrophic, reaching up to 45 and 35 % respectively. In SB-1 in the sample collected from interval 1043–1047 m at the IInd meter, the percentage of eutrophic species amounts to 54 % with 31 % of oligotrophic ones. In turn in S-4 at the depth 1016–1021 II, oligotrophic species (45 %) prevail over the eutrophic ones (35 %) (Table 2, Fig. 16).

At the last depth interval **(850 and 700 m),** within the samples from S-3, distribution of examined paleoecological groups at the beginning, in the sample 834–843 VIII, is characterized by relatively higher abundance of eutrophic species reaching up to 49 %, whereas oligotrophic species is around 42 % (Table 2, Fig. 16). At the same interval, in the sample from IVth meter their percentage is equal, around 40 %. At the interval 715–724 from the IXth meter, oligotrophic species begin to prevail over eutrophic ones. The difference at the IXth and VIIIth meters is the order of a few percent, whereas at the IInd meter is strongly marked reaching up to 22 % and at the last first meter 14 %.

Discussion

The calcareous nannofossils assemblages from the Stobierna 2, Stobierna 3, Stobierna 4, Stadnicka Brzóza 1 and Pogwizdów 2 boreholes are characterized by relatively high percentages of *Coccolithus pelagicus* and *Cyclicargolithus floridanus* assigned to cold-water taxa. The former, which is a subpolar species today, evolved in the tropical area during the Early Cenozoic and changed temperature preference through geological time (Haq & Lohmann 1976; Wei & Wise 1990). *C. pelagicus* is a good paleoclimatic indicator (Haq 1977), which prefers cold (7–14 °C) nutrient rich surface waters (McIntyre & Bé 1976). Its high abundances are related to intense upwelling and unstable stratified water column (Rahmann & Roth 1990), which is typical for coastal environments (Spezzaferri & Ćorić 2001; Ćorić & Rögl 2004). But it is also well known that this species is resistant to the carbonate dissolution. This could result in improvement of its relative frequency within the associations, giving a "cold" aspect to the assemblages (Rahmann & Roth 1990; Vulc & Silye 2005). Additionally due to high redeposition and the long-lasting range of these taxa, the real abundance may differ from the estimated values.

In all profiles small reticulofenestrids were observed very often. The size of coccoliths is associated with seasonal fluctuations in nutrients and temperature (Gartner et al. 1983/1984; Kameo 2002) and thus the frequent occurrence of small reticulofenestrids could be a signal of changes in nutrient dynamic. Its bloom is interpreted as a result of influence of warm waters without upwelling conditions (Ćorić & Rögl 2004).

Pontosphaera multipora occurs at a lower frequency. Occurrence of cribriliths secreted by *Pontosphaera* spp. is considered indicative of shallower marine environments (Bukry 1971; Bybell & Gartner 1972; Roth & Thierstein 1972; Edwards 1973; Müller 1976; Aubry 1990). The *Pontosphaera* spp. shows more variety near shore than in the open oceanic samples (Perch-Nielsen 1972).

Braarudosphaera bigelowii was noticed sporadically. This species was included by Andreyeva-Grigorovich (2002) in the group preferring warm-water conditions. *B. bigelowii* was found mostly in coastal waters (Gran & Braarud 1935; Gaarder 1954; Nishida 1979; Aubry 1989). Previous studies of *Braarudosphaera* spp. enrichments in the open ocean sediments (e.g. Siesser et al. 1992) show that this genus is not necessarily linked to neritic environments but rather to eutrophic waters and reduced competition (see Bartol et al. 2008). Its preference for shallow water has been related to water depth (Takayama 1972) or to lower salinity and higher turbulence (Bramlette & Martini 1964; Martini 1965; Aubry 1989). *B. bigelowii* is an opportunistic species associated with stress conditions (Thierstein et al. 2004; Bartol et al. 2008).

The warm-water group includes *Sphenolithus moriformis* which is numerous in all profiles and the less abundant *S. abies.* The first one is typical for marine basins with normal salinity (Andreyeva-Grigorovich 2002). Its great concentrations were observed in the tropical zones whereas *S. abies* was more common in subtropical provinces (Dmitrenko 1993, fide Andreyeva-Grigorovich 2002).

Nannofossil species *Helicosphaera carteri,* belonging to moderate group, was observed in relatively high numbers in both profiles. The geographical distribution of the living species *H. carteri* has been interpreted as dependent upon water temperature (McIntyre & Bé 1967; Okada & Honjo 1973; Okada & McIntyre 1979; Aubry 1990). *H. carteri* is eurythermal and tolerates water temperature as low as 5 °C and as high as 30 °C (Okada & McIntyre 1979; Aubry 1990), but it is more common in tropical and subtropical nannoflora provinces (Schneidermann 1977). This taxa is interpreted as a "near shore" species (Perch-Nielsen 1985) related to warm shelf and coastal environment. In open ocean it occurs very rarely. Its percentage is changeable along the profiles, but its gradual upward trend is noticeable. Thus the presence of *H. carteri* could indicate a warm, shallow coastal paleoenvironment.

The species of genus *Discoaster*, occurring in both profiles with scarce frequency, could confirm coastal environment as a negative indicator, because discoasterids are more common in open ocean assemblages (cf. Švábenická 2002). However it is not an unambiguous marker of paleoecology. Its distribution depends on paleogeography. It occurs much more often in the Mediterranean area than in the Paratethys (cf. Perch-Nielsen 1985). In addition epicontinental marine sediments usually contain smaller in size and less numerous specimens in comparison with sediments deposited under open ocean conditions (Aubry 1984; Švábenická 2002). Previously it was believed that abundance of discoasterids was associated with latitude and declines with its increase (Wei S. & Wise W. 1990), but some later studies showed that per-

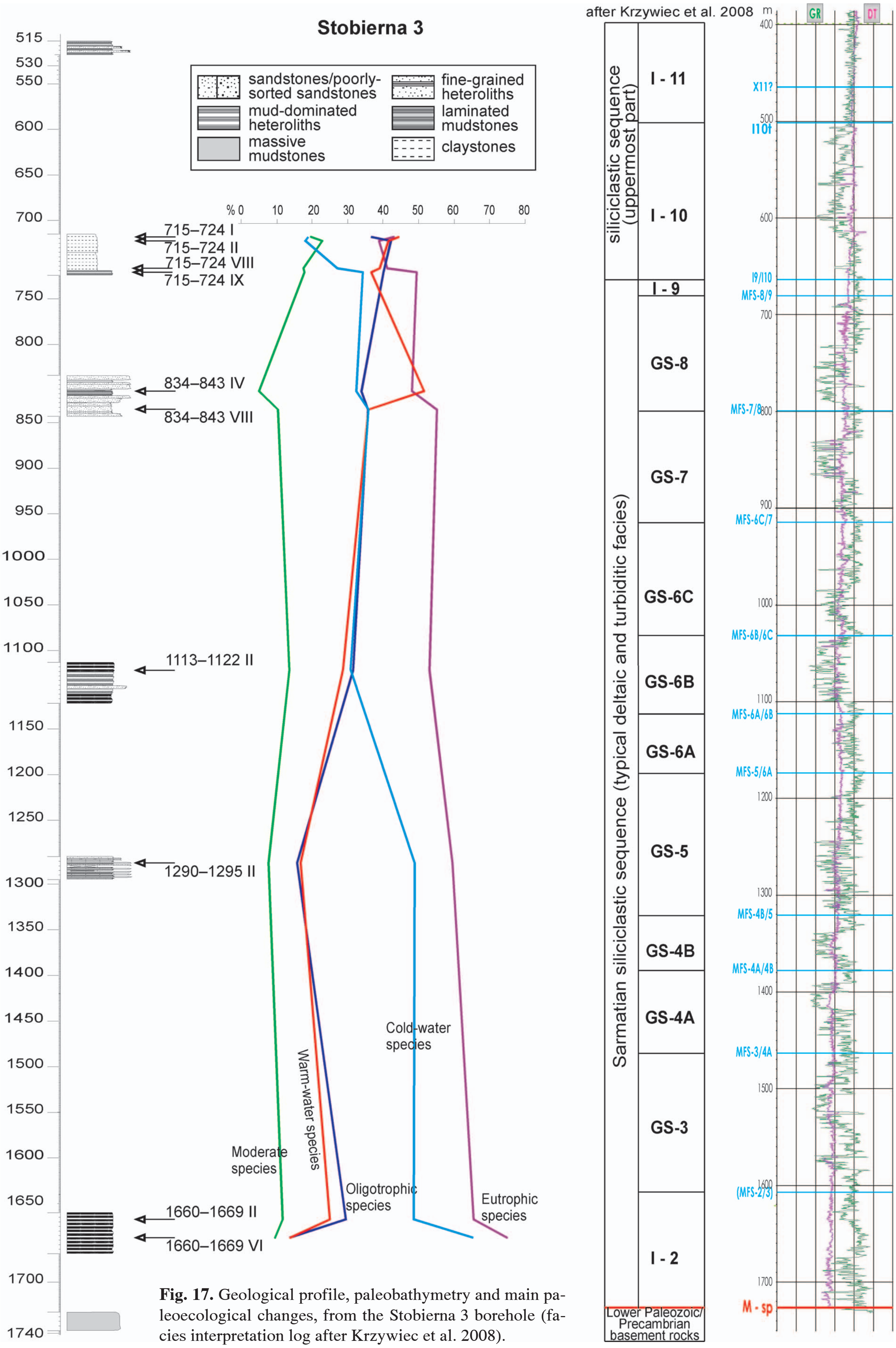


Fig. 17. Geological profile, paleobathymetry and main paleoecological changes, from the Stobierna 3 borehole (facies interpretation log after Krzywiec et al. 2008).

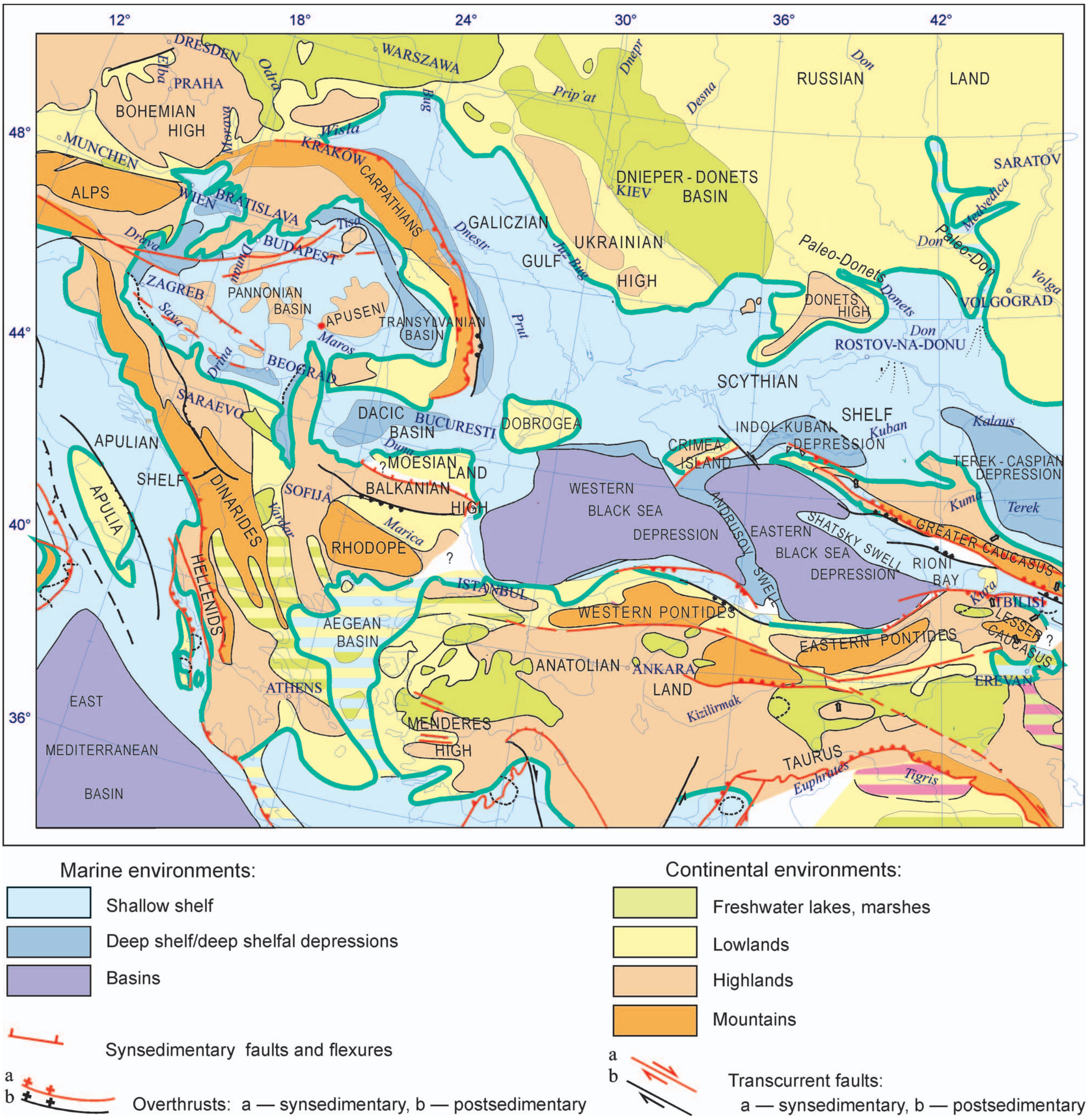


Fig. 18. Paleogeographical map of the Early Sarmatian (based on Popov et al. 2004; Studencka & Jasionowski 2011, simplified).

centage of discoasterids was lower in equatorial regions than in areas of moderate latitudes (Haq & Lohmann 1976). So it would seem that there is no evident dependence between abundance of this group and water temperature. The *Discoaster* genus was considered as a warm-water preferring group whereas among this taxa are known species which could tolerate lower temperature than those found in both profiles: *D. variabilis* and *D. deflandrei*. Aubry (1984) describes them as species which either tolerate or exhibit preference for colder waters (cf. Švábenická 2002).

The characteristic features of the observed nannoplankton assemblages together with high number of redeposited nannofossils are interpreted (Fig. 17) as possible indicators of a shallow near-shore environment. Such interpretation is in agreement with the one proposed by Garecka & Olszewska (2011). According to these authors (Garecka & Olszewska 2011), high number of damaged elements of coccoliths may suggest a strong supply of terrigenous material and unstable conditions in shallow-water basin.

In the early Late Badenian, as a result of the general shallowing and partial isolation of the basin, on the shelf, the sulphate facies of evaporites developed (Krzyżanowice Formation). This was a kind of platform shelf with a width of about 75 km (Oszczypko et al. 2006; Oszczypko 2006), located north of the actual front of the Carpathian nappes. After the evaporite deposition the central part of the Polish Carpathian Foredeep Basin (PCFB) was uplifted and eroded ("Rzeszów Island"). The "Rzeszów Island" can be regarded as a kind of "fore-bulge" connected with the initial period of the "middle-Badenian compression" (the late Styrian compression, see Oszczypko & Oszczypko-Clowes 2011). The formation of the "Rzeszów Island" was followed by a northwards shift of the Carpathian nappes, and initiation of a new phase of subsidence in the Polish Carpathian Foredeep Basin and the beginning of deposition of the Machów Formation (Oszczypko 1998, 1999, 2006). During this time, the depth of the sea oscillated around a depth characteristic of the upper bathyal–neritic zone (Oszczypko 1999). In the eastern part of the Carpathian Foredeep the subsidence axis coincides approximately with the current front of the Carpathians. In the Late Badenian, in the region of Rzeszów, the overall rate of subsidence was 1200–1300 m/Myr, while the rate of sedimentation fluctuated around 1000 m/Myr (Oszczypko 1998, 1999). The Late Badenian (Kosovian) transgression was related to the last, but very intense phase of PCF subsidence that commenced around 13.65 Ma and ended ca. 10.5 Ma during the Sarmatian s.l. During this transgression, the outer and inner neritic conditions were established in the inner and outer parts of the foredeep as well as in the marginal part of the Carpathians (Fig. 18) (see Oszczypko-Clowes et al. 2009; Studencka & Jasionowski 2011; Oszczypko & Oszczypko-Clowes 2011). The southern part of the foredeep basin was supplied with detritic material derived from erosion of Carpathians. This results clearly from log measurements of the paleotransport directions in the Stobierna 2, Stobierna 3 and Pogwizdów 2 boreholes (Krzywiec et al. 2008). It is also confirmed by the presence of reworked nannofossil assemblages. The percentage of reworked species in most samples from the Stobierna 2, Stobierna 3, Stobierna 4, Stadnicka Brzóza 1 and Pogwizdów 2 boreholes prevails over autochthonous specimens (Peryt in Peryt et al. 1998; Garecka & Olszewska 2011). In the Stobierna 3 borehole the supply from the south is already apparent in the lower deltaic complex, whereas in the other three wells, only in the higher deltaic complex. This supply direction remained in the Sarmatian. Only in the highest part of the profile — the last 600–800 meters, the southern direction of supply changes to south-eastern. The distribution of facies suggests multipoint supply through the fan-deltas (Oszczypko et al. 1987). Badenian subsidence continuously passed into the Sarmatian, although the change of direction and position of depocenters was significant, moving from the vicinity of the Carpathians edge into the Wielkie Oczy trench. The total subsidence is here from 1500 m in the NE part of the trench to 2500–3000 m in the SE (Oszczypko 1998, 1999). Development and architecture of the Upper-Sarmatian sediments in the eastern part of the foredeep is probably derived from the interaction of tectonic processes and shallowing-upward changes in sea level. Tectonic processes, including thrust movements of the Outer Carpathians, probably largely determined the size of subsidence in the basin and migration of depocenters, while changes in sea level determined the depth of the reservoir and shoreline shifts.

Conclusion

1. Deposition of the Machów Formation, in Sokołów area, was related to the last, but very intense phase of subsidence in the NE part of the Polish Carpathian Foredeep.

2. This subsidence commenced with the late Styrian compression (latest Badenian) and ended during the Sarmatian s.l.

3. In the studied material reworked nannofossil assemblages prevail over autochthonous specimens. This suggests importance of material supply, derived from eroded Outer Carpathians.

4. The Carpathian supply of siliciclastic material is also documented by the lower and upper deltaic complexes.

5. The obtained quantitative ratios of calcareous nannoplankton taxa show a general character of assemblages indicating a shallow near-shore sedimentary environment.

6. The common occurrence of long-ranging taxa and taxa resistant to carbonate dissolution may affect their real abundance in assemblages, which makes paleoecological interpretation problematic.

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Appendix

Nannofossil taxa mentioned in the text, in alphabetical order of genera

Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre (1947)
Calcidiscus leptoporus (Murray & Blackman, 1898) Loeblich & Tappan (1978)
Calcidiscus macintyrei (Bukry & Bramlette, 1969) Loeblich & Tappan (1978)
Calcidiscus premacintyrei Theodoridis (1984)
Chiasmolithus bidens (Bramlette & Sullivan, 1961) Hay & Mohler (1967)
Chiasmolithus grandis (Bramlette & Riedel, 1954) Radomski (1968)
Chiasmolithus modestus Perch-Nielsen (1971)
Chiasmolithus oamaruensis (Deflandre in Deflandre & Fert, 1954) Hay, Mohler & Wade (1966)
Chiasmolithus solitus (Bramlette & Sullivan, 1961) Hay, Mohler & Wade (1966)
Coccolithus miopelagicus Bukry (1971)
Coccolithus pelagicus (Wallich, 1877) Schiller (1930)
Coronocyclus nitescens (Kamptner, 1963) Bramlette & Wilcoxon (1967)
Cyclicargolithus abisectus (Muller, 1970) Wise (1973)
Cyclicargolithus floridanus (Roth & Hay in Hay et al., 1967) Bukry (1971)
Cyclicargolithus luminis (Sullivan, 1965) Bukry (1971)
Dictyococcites bisectus (Hay, Mohler & Wade, 1966) Bukry & Percival (1971)
Discoaster barbadiensis Tan Sin Hok (1927)
Discoaster binodosus Martini (1958)
Discoaster challengeri Bramlette & Riedel (1954)
Discoaster deflandrei Bramlette & Riedel (1954)
Discoaster distinctus Martini (1958)
Discoaster druggi Bramlette & Wilcoxon (1967)
Discoaster exilis Martini & Bramlette (1963)
Discoaster lodoensis Bramlette & Riedel (1954)
Discoaster mediosus Bramlette & Sullivan (1961)
Discoaster multiradiatus Bramlette & Riedel (1954)
Discoaster saipanensis Bramlette & Riedel (1954)
Discoaster tanii Bramlette & Riedel (1954)
Discoaster tanii nodifer Bramlette & Riedel (1954)
Discoaster variabilis Martini & Bramlette (1963)
Ellipsolithus macellus (Bramlette & Sullivan, 1961) Sullivan (1964)
Ericsonia fenestrata (Deflandre & Fert, 1954) Stradner in Stradner & Edwards (1968)
Ericsonia formosa (Kamptner, 1963) Haq (1971)
Ericsonia subdisticha (Roth & Hay in Hay et al., 1967) Roth in Baumann & Roth (1969)
Helicosphaera ampliaperta Bramlette & Wilcoxon (1967)
Helicosphaera bramlettei (Müller, 1970) Jafar & Martini (1975)
Helicosphaera carteri (Wallich, 1877) Kamptner (1954)
Helicosphaera compacta Bramlette & Wilcoxon (1967)
Helicosphaera euphratis Haq (1966)
Helicosphaera gartneri Theodoridis (1984)
Helicosphaera intermedia Martini (1965)
Helicosphaera lophota (Bramlette & Sullivan, 1961) Locker (1973)
Helicosphaera mediterranea Müller (1981)
Helicosphaera perch-nilseniae Haq (1971)
Helicosphaera recta (Haq, 1966) Jafar & Martini (1975)
Helicosphaera scissura Müller (1981)
Helicosphaera stalis Theodoridis (1984)
Helicosphaera walbersdorfensis Müller (1974)
Helicosphaera waltrans Theodoridis (1984)
Heliolithus kleinpelli Sullivan (1964)
Holodiscolithus macroporus (Deflandre in Deflandre & Fert, 1954) Roth (1970)
Isthmolithus recurvus Deflandre in Deflandre & Fert (1954)
Lanternithus minutus Stradner (1962)
Neococcolithes dubius (Deflandre in Deflandre & Fert, 1954) Black (1967)
Pontosphaera discopora Schiller (1925)
Pontosphaera enormis (Locker, 1967) Perch-Nielsen (1984)
Pontosphaera latelliptica (Báldi-Beke & Baldi, 1974) Perch-Nielsen (1984)
Pontosphaera multipora (Kamptner ex Deflandre, 1959) Roth (1970)
Pontosphaera plana (Bramlette & Sullivan, 1961) Haq (1971)
Pontosphaera rothi Haq (1971)
Reticulofenestra daviessi (Haq, 1971) Haq (1971)
Reticulofenestra dictyoda (Deflandré in Deflandré & Fert, 1954) Stradner in Stradner & Edwards (1968)
Reticulofenestra hillae Bukry & Percival (1971)
Reticulofenestra lockerii Müller (1970)
Reticulofenestra ornata Müller (1970)
Reticulofenestra pseudoumbilica (Gartner, 1967) Gartner (1969)
Reticulofenestra reticulata (Hay, Mohler & Wade, 1966) Roth (1970)
Reticulofenestra umbilica (Levin, 1965) Martini & Ritzkowski (1968)
Rhabdosphaera clavigera Murray & Blackman (1898)
Semihololithus kerabyi Perch-Nielsen (1971)
Sphenolithus abies Deflandre in Deflandre & Fert (1954)
Sphenolithus belemnos Bramlette & Wilcoxon (1967)
Sphenolithus capricornutus Bukry & Percival (1971)
Sphenolithus conicus Bukry (1971)
Sphenolithus dissimilis Bukry & Percival (1971)
Sphenolithus editus Perch-Nielsen in Perch-Nielsen et al. (1978)
Sphenolithus heteromorphus Deflandre (1953)
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon (1967)
Sphenolithus radians Deflandre in Grassé (1952)
Sphenolithus spiniger Bukry (1971)
Toweius rotundus Perch-Nielsen in Perch-Nielsen et al. (1978)
Transversopontis fibula Getha (1976)
Transversopontis obliquipons (Deflandre in Deflandre & Fert, 1954) Hay, Mohler & Wade (1966)
Transversopontis pulcher (Deflandre in Deflandre & Fert, 1954) Perch-Nielsen (1967)
Transversopontis pulcheroides (Sullivan, 1964) Báldi-Beke (1971)
Transversopontis pygmaea Locker (1967)
Tribrachiatus orthostylus Shamrai (1963)
Triquetrorhabdulus rugosus Bramlette & Wilcoxon (1967)
Umbilicosphaera rotula (Kamptner, 1956) Varol (1982)
Zygrhablithus bijugatus (Deflandre in Deflandre & Fert, 1954) Deflandre (1959)

Table 3: Nominal and percentage distribution of calcareous nannofossils in the Stobierna 2 borehole. x — species too rare to be included in count.

Stobierna 2	1190–1208 XVI		1190–1208 I		1208–1222 X		1320–1338 IV		1320–1338 XIII	
Autochthonous species										
Braarudosphaera bigelowii	1	0.67	4	3.10	1	0.68	1	0.58	1	0.63
Calcidiscus leptoporus			x							
Calcidiscus macintyrei	1	0.67							1	0.63
Calcidiscus premacintyrei	x				1	0.68	1	0.58	2	1.25
Coccolithus miopelagicus	4	2.67	2	1.55	4	2.70	2	1.16	5	3.13
Coccolithus pelagicus	33	22.00	22	17.05	26	17.57	45	26.01	29	18.13
Coronocyclus nitescens	1	0.67	3	2.33	4	2.70	3	1.73	2	1.25
Cyclicargolithus floridanus	36	24.00	30	23.26	31	20.95	55	31.79	30	18.75
Discoaster deflandrei					1	0.68	1	0.58	2	1.25
Discoaster exilis	1	0.67	x							
Discoaster variabilis			x							
Helicosphaera carteri	22	14.67	x		11	7.43	2	1.16	19	11.88
Helicosphaera intermedia	x		1	0.78	1	0.68	1	0.58	1	0.63
Helicosphaera stalis	1	0.67	x		4	2.70	1	0.58	1	0.63
Helicosphaera walbersdorfensis	4	2.67	6	4.65	1	0.68	3	1.73	6	3.75
Pontosphaera discopora	4	2.67	1	0.78	3	2.03	1	0.58	2	1.25
Pontosphaera multipora	4	2.67	8	6.20	5	3.38	x		3	1.88
Reticulofenestra pseudoumbilica	9	6.00	8	6.20	23	15.54	26	15.03	21	13.13
Reticulofenestra spp. small	13	8.67	27	20.93	10	6.76	12	6.94	21	13.13
Sphenolithus abies	2	1.33	3	2.33	7	4.73	8	4.62	1	0.63
Sphenolithus moriformis	12	8.00	10	7.75	13	8.78	10	5.78	10	6.25
Umbilicosphaera rotula	2	1.33	4	3.10	2	1.35	1	0.58	3	1.88
Allochthonous species										
Chiasmolithus bidens					1					
Chiasmolithus grandis	x				1				1	
Chiasmolithus modestus					2		x		1	
Chiasmolithus oamaruensis	2		1		3		1		1	
Chiasmolithus solitus	x		2		1				1	
Cyclicargolithus abisectus	13		12		10		13		7	
Cyclicargolithus luminis	1									
Dictyococcites bisectus	28		33		28		53		22	
Discoaster barbadiensis	1		1		1		2		1	
Discoaster binodosus	1		1		2					
Discoaster druggi			1							
Discoaster lodoensis	1		x						1	
Discoaster multiradiatus			1							
Discoaster tanii	1									
Discoaster tanii nodifer									1	
Ericsonia fenestrata	5		7		x		x		1	
Ericsonia formosa	7		8		12		3		14	
Helicosphaera bramlettei	2		2		5				2	
Helicosphaera compacta	1		8						1	
Helicosphaera euphratis	x		x		1		1			
Helicosphaera gartneri	x		1							
Helicosphaera mediterranea			1		1		1		3	
Helicosphaera recta	x		x		1		1			
Helicosphaera scissura					1				4	
Heliolithus kleinpelli	3		2		3				1	
Isthmolithus recurvus			4		2				1	
Lanternithus minutus	5		13		4		8		2	
Neococcolithes dubius	x								1	
Pontosphaera enormis	x				x					
Pontosphaera latelliptica	15		9		10		7		14	
Pontosphaera plana	1		2				1		1	
Pontosphaera rothi			x		x		1			
Reticulofenestra daviessi	2		6		9		7		12	
Reticulofenestra dictyoda	5		5		5		1			
Reticulofenestra hillae	1									
Reticulofenestra lockerii	1		x		1					
Reticulofenestra ornata	16		12		1		6		8	
Reticulofenestra reticulata	6		4		14		2		8	
Reticulofenestra umbilica	9		8		10		x		11	
Sphenolithus conicus	1		1		1		2		1	
Sphenolithus dissilimis	x		1		1				x	
Sphenolithus editus									2	
Sphenolithus heteromorphus	2		1		1		1		1	
Sphenolithus radians	x		x		2		1			
Transversopontis obliquipons	1		2		1		1		1	
Transversopontis pulcher	1		3		1		1		1	
Transversopontis pulcheroides	2		1		2		1		1	
Transversopontis pygmaea			x		1				1	
Tribrachiatus orthostylus							1		1	
Zygrhablithus bijugatus	1		7		3		x		2	
Cretaceous species undivided	15		11		10		11		9	
SUM	300		300		300		300		300	

Table 4: Nominal and percentage distribution of calcareous nannofossils in the Stobierna 3 borehole. x — species too rare to be included in count.

Stobierna 3	715–724 I		715–724 II		715–724 VIII		715–724 IX		834–843 IV		834–843 VIII		1113–1122 II		1290–1295 II		1660–1669 II		1660-1669 VI	
Autochthonous species																				
Braarudosphaera bigelowii	3	2.19	2	1.34	1	0.74	1	0.85	1	0.85	x						x			
Calcidiscus leptoporus	7	5.11	9	6.04	7	5.15	1	0.85			1	0.75					1	0.84	5	2.98
Calcidiscus premacintyrei													1	0.32	1	0.36			1	0.33
Coccolithus miopelagicus >10 µm	10	7.30	8	5.37	6	4.41	5	4.27	9	7.63	4	2.99								
Coccolithus miopelagicus	4	2.92	x		3	2.21	x		8	6.78	x		6	1.90	5	1.78			2	0.67
Coccolithus pelagicus	10	7.30	14	9.40	13	9.56	16	13.68	14	11.86	18	13.43	13	9.35	32	20.92	30	25.21	53	31.55
Coronocyclus nitescens													10	3.17	19	6.76	2	0.66	2	0.67
Cyclicargolithus floridanus	13	9.49	10	6.71	23	16.91	21	17.95	15	12.71	22	16.42	18	12.95	33	21.57	28	23.53	50	29.76
Discoaster deflandrei									1	0.85	3	2.24	2	1.44						
Discoaster variabilis									2	1.69	1	0.75								
Helicosphaera carteri	12	8.76	18	12.08	13	9.56	17	14.53	6	5.08	7	5.22	11	7.91	8	5.23	7	5.88	2	1.19
Helicosphaera intermedia	3	2.19	2	1.34	2	1.47	2	1.71			6	4.48	2	1.44	1	0.65	5	4.20	1	0.60
Helicosphaera walbersdorfensis	5	3.65	5	3.36	2	1.47	1	0.85	x		x		5	3.60	2	1.31	1	0.84	7	4.17
Pontosphaera discopora	2	1.46	4	2.68	1	0.74	2	1.71	3	2.54	1	0.75	5	3.60	3	1.96	3	2.52	3	1.79
Pontosphaera multipora	14	10.22	11	7.38	12	8.82	5	4.27	6	5.08	16	11.94	15	10.79	3	1.96	9	7.56	4	2.38
Reticulofenestra pseudoumbilica	3	2.19	3	2.01	1	0.74	3	2.56	9	7.63	8	5.97	12	8.63	10	6.54	x		7	4.17
Reticulofenestra spp. *small*	14	10.22	14	9.40	5	3.68	10	8.55	9	7.63	9	6.72	11	7.91	10	6.54	8	6.72	9	5.36
Sphenolithus abies	13	9.49	14	9.40	16	11.76	10	8.55	10	8.47	8	5.97	8	5.76	3	1.96	3	2.52	3	1.79
Sphenolithus moriformis	17	12.41	24	16.11	22	16.18	17	14.53	21	17.80	23	17.16	16	11.51	10	6.54	19	15.97	10	5.95
Umbilicosphaera rotula	7	5.11	11	7.38	9	6.62	6	5.13	4	3.39	7	5.22	4	2.88	13	8.50	3	2.52	9	5.36
Allochthonous species																				
Calcidiscus premacintyrei			2		1															
Chiasmolithus bidens																	1		1	
Chiasmolithus modestus	1		2						1											
Chiasmolithus oamaruensis									1		1									
Chiasmolithus solitus					1												1			
Coronocyclus nitescens	8		9		13		16		10		12									
Cyclicargolithus abisectus	11		8		8		13		9		7		1		4		3		10	
Cyclicargolithus luminis							1		2								1			
Dictyococcites bisectus	17		23		25		26		21		17		21		14		29		6	
Discoaster barbadiensis			1		2		1		1				3				1			
Discoaster binodosus									3				1							
Discoaster lodoensis			1		1				2		1									
Discoaster multiradiatus									1											
Discoaster saipanensis			1		1								1							
Discoaster sp.			2				4		1				1				1			
Discoaster tanii									1				1							
Discoaster tanii nodifer													1							
Ericsonia fenestrata	1		4		2				2		4		4				6		3	
Ericsonia formosa	13		12		17		19		15		8		13		11		20		17	
Ericsonia subdisticha	5		2										5						3	
Helicosphaera bramletei			1		2		2		3						1					
Helicosphaera euphratis	2								1		3						3		2	
Helicosphaera gartneri	2		4		3		2				2		4		2				2	
Helicosphaera mediterranea	1				1		1				1		1		1					
Helicosphaera recta	1				2		1		1				1				1			
Helicosphaera scissura	1		4		3		2		1		5		3		2		3		1	
Helicosphaera sp.			3								1		2				1		1	
Helicosphaera waltrans	1		1				1													
Isthmolithus recurvus			5				1		6		3		7		1					
Lanternithus minutus	12		6		17		14		7		8		9		3		5		1	
Neococcolithes dubius									3											
Pontosphaera latelliptica	11		7		13		12		12		17		19		6		6		4	
Pontosphaera plana																	1			
Pontosphaera rothi	1				1				1		3		2							
Reticulofenestra dictyoda	7		3		2		5		5		4		2				8		2	
Reticulofenestra hillae	3		3		4		4		14		5		11		2		6		1	
Reticulofenestra lockerii	9		1		x		2		x		1		5		3		5		2	
Reticulofenestra ornata	9		8		8		7		6		15		10		7		16		18	
Reticulofenestra reticulata	7		11		2		6		9		7		5		10		8		3	
Reticulofenestra umbilica	3		4		7		8		10		8				8		2		1	
Sphenolithus belemnos	2		2		2															
Sphenolithus conicus											1						1		2	
Sphenolithus dissilimis			2		2				1		3		3				2			
Sphenolithus heteromorphus	6		3		1		3				1						1			
Sphenolithus radians	5						5		4		2		4		1		3		3	
Toweius rotundus							4										8		2	
Transversopontis obliquipons	1		1		2		2		1		1									
Transversopontis pulcher			1		1		1		3		2		2				1		2	
Transversopontis pulcheroides									2		1		2				1		1	
Zygrhablithus bijugatus	5		2		5		3		11		9		5		5		2			
Cretaceous species undivided	18		12		15		17		11		13		12		33		23		28	
SUM	300		300		300		300		300		300		300		267		289		284	

Table 5: Nominal and percentage distribution of calcareous nannofossils in the Stobierna 4 borehole. x — species too rare to be included in count.

Stobierna 4	1016–1021 II		1116–1125 I		1116–1125 IV		1116–1125 IX		1229–1238 V		1229–1238 VII		1229–1238 VIII	
Autochthonous species														
Braarudosphaera bigelowii	3	2.19	4	2.61			2	1.44	1	0.78	6	3.61	3	1.83
Calcidiscus leptoporus	3	2.19	3	1.96	2	1.61	1	0.72	1	0.78	2	1.20	1	0.61
Calcidiscus premacintyrei			7	4.58			5	3.60			1	0.60	5	3.05
Coccolithus miopelagicus	8	5.84	1	0.65			6	4.32	3	2.34	5	3.01	6	3.66
Coccolithus pelagicus	14	10.22	15	9.80	30	24.19	13	9.35	13	10.16	19	11.45	18	10.98
Coronocyclus nitescens	6	4.38	6	3.92	4	3.23	9	6.47	11	8.59	13	7.83	14	8.54
Cyclicargolithus floridanus	9	6.57	11	7.19	43	34.68	15	10.79	16	12.50	18	10.84	19	11.59
Discoaster deflandrei	4	2.92	1	0.65			1	0.72	2	1.56			1	0.61
Helicosphaera carteri	14	10.22	23	15.03	8	6.45	11	7.91	26	20.31	22	13.25	15	9.15
Helicosphaera intermedia	7	5.11	6	3.92	1	0.81	1	0.72	1	0.78	1	0.60	2	1.22
Helicosphaera walbersdorfensis	4	2.92	1	0.65	3	2.42	3	2.16	4	3.13	3	1.81	2	1.22
Pontosphaera discopora	13	9.49	9	5.88	3	2.42	4	2.88			6	3.61	6	3.66
Pontosphaera multipora	5	3.65	10	6.54	2	1.61	9	6.47	8	6.25	3	1.81	7	4.27
Reticulofenestra pseudoumbilica	4	2.92	x		1	0.81	11	7.91	3	2.34	14	8.43	2	1.22
Reticulofenestra spp. small	13	9.49	16	10.46	9	7.26	11	7.91	8	6.25	7	4.22	12	7.32
Rhabdosphaera clavigera	3	2.19	1	0.65										
Sphenolithus abies	9	6.57	4	2.61	4	3.23	5	3.60	4	3.13	7	4.22	5	3.05
Sphenolithus moriformis	11	8.03	24	15.69	12	9.68	22	15.83	15	11.72	29	17.47	34	20.73
Umbilicosphaera rotula	7	5.11	11	7.19	2	1.61	10	7.19	12	9.38	10	6.02	12	7.32
Allochthonous species														
Chiasmolithus bidens											1			
Chiasmolithus modestus											1			
Chiasmolithus oamaruensis							1							
Chiasmolithus solitus	2		3		1									
Cyclicargolithus abisectus	8		4		4		4		7		4		3	
Cyclicargolithus luminis	2				1				1		1		1	
Dictyococcites bisectus	21		22		20		26		19		21		18	
Discoaster barbadiensis	3		1		1		2		4		1		1	
Discoaster binodosus	1		1				1		1					
Discoaster lodoensis	2		1				2		1					
Discoaster multiradiatus					2						1			
Discoaster saipanensis			3		1				1					
Discoaster sp.	1				3		2		3					
Discoaster tanii					2		1							
Discoaster tanii nodifer									1				1	
Ericsonia fenestrata	7		5		2		11		2		1		7	
Ericsonia formosa	8		9		16		11		18		11		13	
Ericsonia subdisticha	1		2		1		2							
Helicosphaera bramlettei	1		6		1		1		2		1		2	
Helicosphaera euphratis			1						1				1	
Helicosphaera gartneri	1		3								2			
Helicosphaera mediterranea	1		1										2	
Helicosphaera perch-nilseniae					1						1			
Helicosphaera recta							1						1	
Helicosphaera scissura	3		4		2				8				1	
Helicosphaera sp.			2				2				3		2	
Helicosphaera waltrans					1									
Isthmolithus recurvus	6		3				3		6		1		6	
Lanternithus minutus	10		8		1		10		3		4		7	
Neococcolithes dubius	2						1		1					
Pontosphaera latelliptica	10		9		3		5		14		9		7	
Pontosphaera plana									1		2		1	
Pontosphaera rothi	4		3								2		3	
Reticulofenestra dictyoda			1				2		4		4			
Reticulofenestra hillae	11		2				7		4		1		3	
Reticulofenestra lockerii	5		2		5		1		6		2		2	
Reticulofenestra ornata	12		6		8		9		8		13		3	
Reticulofenestra reticulata	6		4		6		14		12		5		10	
Reticulofenestra umbilica	5		8		4		6		6		2		7	
Sphenolithus dissimilis			1				3		1				1	
Sphenolithus heteromorphus	1		2								1		1	
Sphenolithus radians	1		2		1				4		1		3	
Toweius rotundus	x				3		4				2			
Transversopontis obliquipons	1		1		1		1		1		1		4	
Transversopontis pulcher	3		3				1						1	
Transversopontis pulcheroides	6		1				1		x				2	
Tribrachiatus orthostylus	2		1		2				1		1			
Zygrhablithus bijugatus	7		9		2		8		13		2		4	
Cretaceous species undivided	9		13		27		18		18		19		18	
SUM	300		300		246		300		300		287		300	

Table 6: Nominal and percentage distribution of calcareous nannofossils in the Pogwizdów 2 borehole. x — species too rare to be included in count.

Pogwizdów 2	**1161–1170 I**		**1161–1170 VIII**		**1381–1390 II**		**1381–1390 IX**	
Autochthonous species								
Braarudosphaera bigelowii	2	1.64	x		x		x	
Calcidiscus leptoporus	1	0.82					1	1
Calcidiscus macintyrei	x							
Calcidiscus premacintyrei					1	1	14	8
Coccolithus miopelagicus	x		x		2	1	3	2
Coccolithus pelagicus	30	24.59	33	26	40	25	56	30
Coronocyclus nitescens	12	9.84	6	5	13	8	19	10
Cyclicargolithus floridanus	28	22.95	31	24	38	23	57	31
Discoaster challengeri	x		1	1				
Discoaster deflandrei	1	0.82	x		1	0.32	x	
Discoaster variabilis	x		x					
Helicosphaera carteri	5	4.10	7	5	5	3	1	1
Helicosphaera intermedia	1	0.82	3	2			x	
Helicosphaera stalis	1	0.82	1	1	x		1	1
Helicosphaera walbersdorfensis	2	1.64	2	2	4	2	6	3
Holodiscolithus macroporus	x				x		x	
Pontosphaera discopora	4	3.28	1	1	1	1	1	1
Pontosphaera multipora	2	1.64	14	11	6	4	1	1
Reticulofenestra pseudoumbilica	3	2.46	2	2	32	20	1	1
Reticulofenestra spp. small	10	8.20	13	10	10	6	12	6
Rhabdosphaera clavigera	1	0.82						
Sphenolithus abies	1	0.82	2	2	1	1	4	2
Sphenolithus moriformis	15	12.30	11	9	6	4	8	4
Triquetrorhabdulus rugosus	x							
Umbilicosphaera rotula	3	2.46	1	1	2	1	1	1
Allochthonous species								
Chiasmolithus bidens	1		3		2			
Chiasmolithus grandis	1							
Chiasmolithus modestus	1							
Chiasmolithus oamaruensis	1				1			
Chiasmolithus solitus	1		x					
Cyclicargolithus abisectus	10		14		11		12	
Cyclicargolithus luminis	2		3		1		1	
Dictyococcites bisectus	35		27		36		20	
Discoaster barbadiensis	1				1			
Discoaster binodosus	x				x			
Discoaster distinctus	1							
Discoaster druggi							1	
Discoaster lodoensis	1		x					
Discoaster mediosus	x							
Discoaster multiradiatus	1		1		1			
Discoaster saipanensis	1							
Discoaster tanii	2		1		1		1	
Discoaster tanii nodifer	1							
Ellipsolithus macellus	x							
Ericsonia fenestrata	4		8		1		1	
Ericsonia formosa	12		12		6		7	
Helicosphaera ampliaperta					1			
Helicosphaera bramlettei	5		4				2	
Helicosphaera compacta	1				x		2	
Helicosphaera euphratis	1		1				x	
Helicosphaera gartneri	x		1		1			
Helicosphaera lophota	1							
Helicosphaera mediterranea	x		x					
Helicosphaera recta	x		x		1		x	
Helicosphaera scissura	1				4			
Isthmolithus recurvus	2		3		x		x	
Lanternithus minutus	10		13		7		7	
Neococcolithes dubius	2				1		1	
Pontosphaera enormis					x			
Pontosphaera latelliptica	11		15		3		2	
Pontosphaera plana	1		x					
Pontosphaera rothi	2		2		1		1	
Reticulofenestra daviessi	6		6		8		8	
Reticulofenestra dictyoda	1		2		3			
Reticulofenestra lockerii	2		1		3		2	
Reticulofenestra ornata	2		3		3		4	
Reticulofenestra reticulata	17		11		7		7	
Reticulofenestra umbilica	8		8		5		1	
Allochthonous species								
Semihololithus kerabyi			5		1			
Sphenolithus capricornutus	1							
Sphenolithus conicus	4		1		5		1	
Sphenolithus dissilimis	2		1		1		2	
Sphenolithus editus	2		4				x	
Sphenolithus heteromorphus	1		2					
Sphenolithus radians	1				1		1	
Sphenolithus spiniger			2		1			
Toweius sp.	1				3		3	
Transversopontis fibula	x						1	
Transversopontis obliquipons	1		3		x			
Transversopontis pulcher	2		3		3			
Transversopontis pulcheroides	3		1		1			
Transversopontis pygmaea	x				x			
Tribrachiatus orthostylus	x		x		1			
Zygrhablithus bijugatus	6		3		4		6	
Cretaceous spieces undivided	5		8		8		20	
SUM	300		300		300		300	

Table 7: Nominal and percentage distribution of calcareous nannofossils in the Stadnicka Brzóza 1 borehole. x — species too rare to be included in count. *Continued on the next page.*

Stadnicka Brzóza 1	350–356 I		1043–1047 II		1175–1179 III		1327–1331 II		1586–1590		1586–1590 I		1663–1667 III	
Autochthonous species														
Braarudosphaera bigelowii	1	0.83	1	0.79	1	0.80	1	0.72	1	0.83			x	
Calcidiscus leptoporus	x													
Calcidiscus macintyrei														
Calcidiscus premacintyrei					1	0.80			x		x		x	
Coccolithus miopelagicus	x		12	9.45	8	6.40	7	5.07	4	3.31	2	1.40	2	1.74
Coccolithus miopelagicus >10 µm	4	3.31												
Coccolithus pelagicus	33	27.27	28	22.05	41	32.80	38	27.54	29	23.97	47	32.87	25	21.74
Coronocyclus nitescens			3	2.36	4	3.20	1	0.72	9	7.44	5	3.50	3	2.61
Cyclicargolithus floridanus	31	25.62	25	19.69	35	28.00	36	26.09	25	20.66	44	30.77	22	19.13
Discoaster challengeri	x													
Discoaster deflandrei	5	4.13	3	2.36	x		x				x			
Discoaster exilis	x		1	0.79										
Discoaster variabilis	1	0.83												
Helicosphaera carteri	8	6.61	8	6.30	x		7	5.07	8	6.61	7	4.90	14	12.17
Helicosphaera intermedia	x		3	2.36					1	0.83			1	0.87
Helicosphaera stalis	1	0.83	2	1.57	x		x		x		x		6	5.22
Helicosphaera walbersdorfensis	2	1.65	3	2.36	2	1.60	8	5.80	4	3.31	8	5.59	3	2.61
Holodiscolithus macroporus	x		x		x						x			
Pontosphaera discopora	5	4.13	1	0.79			4	2.90	4	3.31	1	0.70	2	1.74
Pontosphaera multipora	5	4.13	11	8.66	5	4.00	2	1.45	6	4.96	2	1.40	12	10.43
Reticulofenestra pseudoumbilica	2	1.65	2	1.57	3	2.40	16	11.59	12	9.92	9	6.29	11	9.57
Reticulofenestra spp. small	9	7.44	9	7.09	7	5.60	6	4.35	2	1.65	7	4.90	10	8.70
Rhabdosphaera clavigera		0.00	2	1.57							1	0.70		
Sphenolithus abies	4	3.31	1	0.79	3	2.40	2	1.45	3	2.48	5	3.50	1	0.87
Sphenolithus moriformis	8	6.61	10	7.87	11	8.80	8	5.80	10	8.26	4	2.80	x	
Triquetrorhabdulus rugosus	x				x									
Umbilicosphaera rotula	2	1.65	2	1.57	4	3.20	2	1.45	3	2.48	1	0.70	3	2.61
Allochthonous species														
Calcidiscus macintyrei	x													
Calcidiscus premacintyrei	x													
Chiasmolithus bidens					1									
Chiasmolithus grandis	1		1				1		1					
Chiasmolithus modestus														
Chiasmolithus oamaruensis	2								1				1	
Chiasmolithus solitus	1		3		1		1		x		x			
Coronocyclus nitescens	6													
Cyclicargolithus abisectus	7		4		16		13		19		16		23	
Cyclicargolithus luminis					3				2		1			
Dictyococcites bisectus	25		22		28		33		33		44		35	
Discoaster barbadiensis	5		4		2		3		1		1		3	
Discoaster binodosus	1								2				1	
Discoaster druggi							1							
Discoaster lodoensis	2						x		x				2	
Discoaster multiradiatus	1		1				x							
Discoaster saipanensis			1											
Discoaster tanii													1	
Ericsonia fenestrata	6		2		5		3		x		5		4	
Ericsonia formosa	15		10		14		17		11		9		14	
Helicosphaera bramlettei	3		1		16		x						1	
Helicosphaera compacta	1		2											
Helicosphaera euphratis	x		x		x		1		x				x	
Helicosphaera gartneri	1		1						1		x		x	
Helicosphaera mediterranea	x		x										x	
Helicosphaera recta	1		1				x		1		x		2	
Heliolithus kleinpelli									4		3		1	
Isthmolithus recurvus	4		2		2		5		x		x		1	
Lanternithus minutus	11		7		13		5		10		7		10	
Neococcolithes dubius	2		1		1				1		1		1	
Pontosphaera enormis					x		x		x		x			
Pontosphaera latelliptica	14		34		3		2		14		5		11	
Pontosphaera plana	x		1				x		2				x	
Pontosphaera rothi	3		1		x				1					
Reticulofenestra daviessi	6		7		12		11		9		4		3	
Reticulofenestra dictyoda			4		6		8		8		7		8	
Reticulofenestra hillae					2									
Reticulofenestra hillae									1					
Reticulofenestra lockerii	x		x		1		1		x		1		2	
Reticulofenestra minuta			x				x				x		x	
Reticulofenestra ornata	5		8		8		8		10		2		10	
Reticulofenestra reticulata	8		9		15		13		14		20		5	
Reticulofenestra umbilica	16		24		3		13		8		7		2	

Table 7: *Continued.*

Stadnicka Brzóza 1	**350–356 I**	**1043–1047 II**	**1175–1179 III**	**1327–1331 II**	**1586–1590**	**1586–1590 I**	**1663–1667 III**
Allochthonous species							
Semihololithus kerabyi	1						
Sphenolithus conicus	1	4		1	1	1	2
Sphenolithus dissilimis			x	x	1	1	
Sphenolithus editus	2		1		1		1
Sphenolithus heteromorphus	2			x	1	2	3
Sphenolithus radians	1				x	1	16
Toweius sp.				3	1		
Transversopontis fibula	1	1	x			x	
Transversopontis obliquipons	3	2		2		2	
Transversopontis pulcher	x	2	3	2	3	x	3
Transversopontis pulcheroides	2	x					x
Transversopontis pygmaea	x			x			
Tribrachiatus orthostylus	1	2		2	1	1	1
Zygrhablithus bijugatus	2	5	3	1	2	1	1
Cretaceous species undivided	16	6	16	12	14	15	17
SUM	300	300	300	300	300	300	300